Exploring the possibility of studying the Drell-Yang process in the SPD (NICA) experiment.

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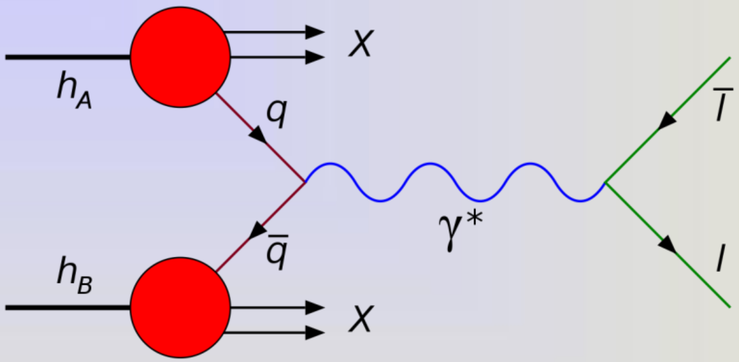


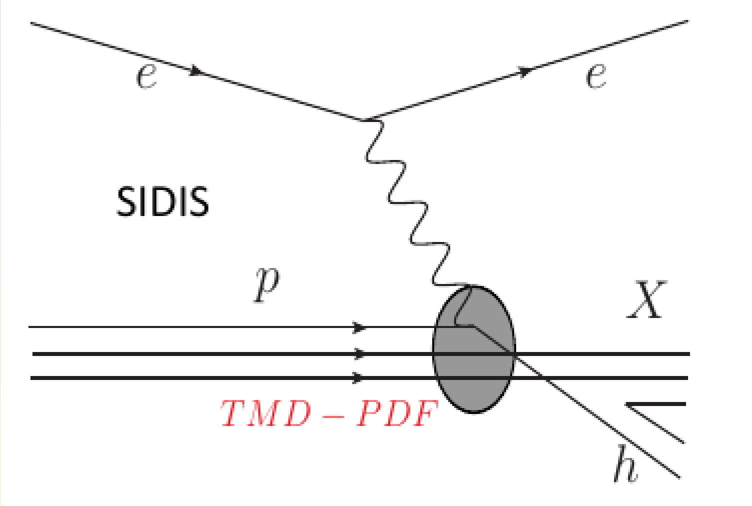
The Drell-Yan processes are collisions of hadrons at high energies, which give rise to a neutral gauge boson — a virtual photon or a weak Z0 boson - during the interaction of a quark and an antiquark, which then decays into a pair of oppositely charged leptons

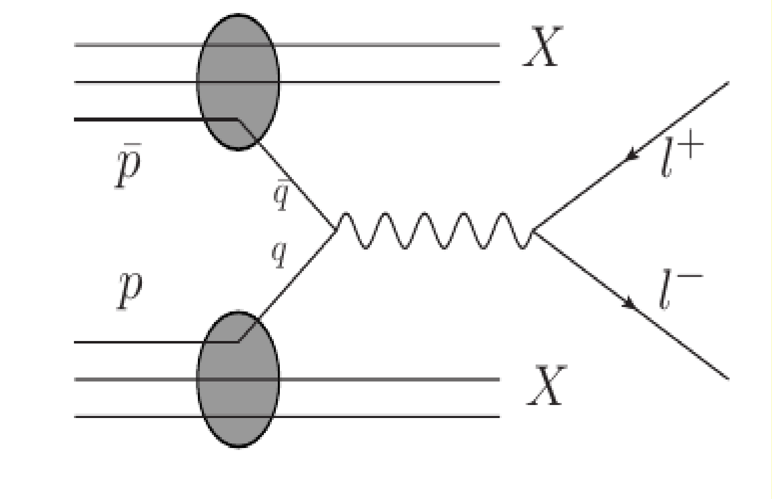
They are **unique processes for the study of spin effects** in hadron interactions, which **allow access to parton distributions** *(describing the distributions of quarks and gluons in hadrons (nuclei) by two variables:* ***x*** *(the fraction of the longitudinal moment k of the hadron carried by the active parton) and* ***pT*** *(the transverse momentum of the active parton))* and **extract new information about the structure of nuclear matter and elementary particles**.

Precision extraction of parton distributions from some experimental data makes it possible to use them for predictions in other physical processes.

Experimental studies of the Drell-Yan processes make it possible to directly measure various spin asymmetries in collisions of unpolarized, transversely and longitudinally polarized hadrons.

Drell-Yang reactions are an important complement to other reactions (such as, for example, semi-inclusive deep-elastic scattering reactions (SIDIS)).



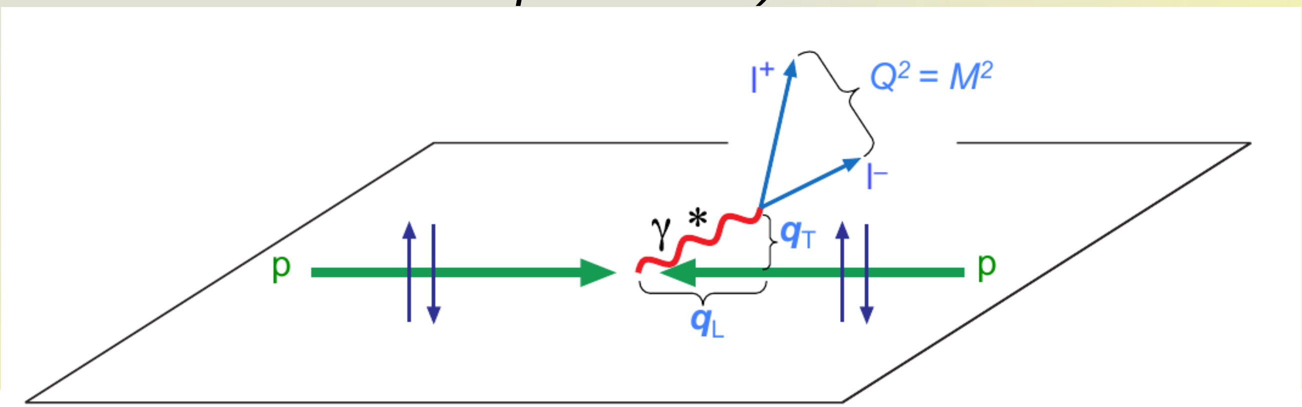


TMD-PDF
related to fragmentation functions

Why Drell-Yan? –
Direct access to TMD-PDFs

With respect to DIS (inclusive or semi-inclusive) by rotating the Feynman diagram, Drell-Yan is an s-channel process, and SIDIS is a t-channel process

The analysis of the measured spin characteristics allows us to extract information about the parton pulse distributions TMD *(relative to the transverse and longitudinal pulse of the active parton)* and PDF *(relative to the longitudinal pulse of the active parton)*, **which are universal non-perturbative functions** *(describing effects at large distances / or at small pulse values)*, **independent of the type of physical process characteristics** *(with the exception of T-odd TMD (T-odd TMD of Boer-Mulders and Sievers), changing the sign in the SIDIS and Drell-Yan processes).*



Partonic distributions *are matrix elements of operators constructed in terms of quark and gluon fields and averaged over hadron states (vacuum states)*

$$d\sigma^{D-Y} = \sum_q f_q(x_1, \boldsymbol{k}_{\perp 1}; Q^2) \otimes f_{\bar{q}}(x_2, \boldsymbol{k}_{\perp 2}; Q^2)\, d\hat{\sigma}^{q\bar{q}\to \ell^+\ell^-}$$

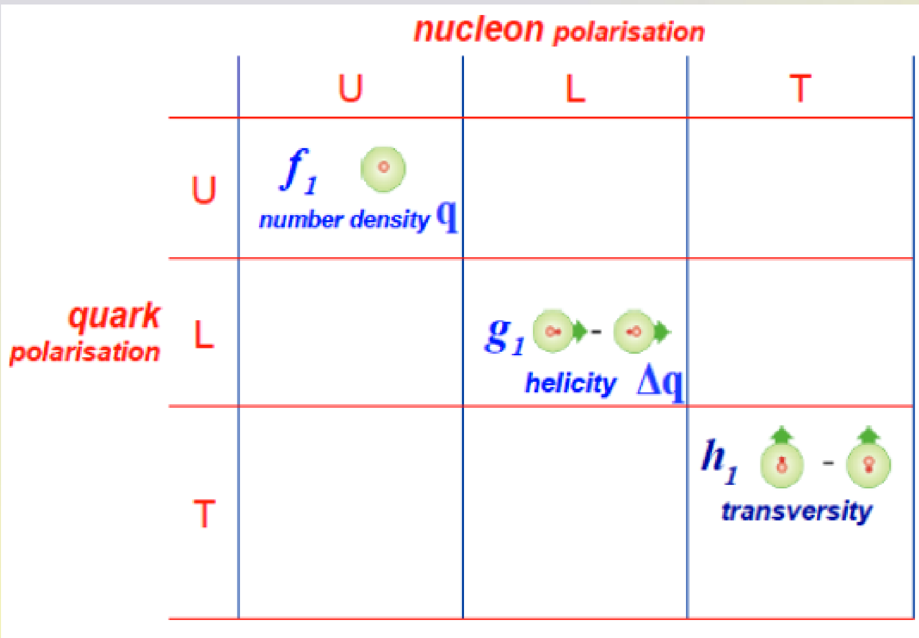
To extract ***PDF distributions***, the most suitable conditions are when $M^{l+l-}{}_{inv}$ (=Q - transmitted 4- momentum) and PT^{l+l} are of the same order.

To extract information about **TMD distributions**, the scale of $M^{l+l-}{}_{inv}$ (=Q) >> PT^{l+l-} of lepton pair ~= transverse momentum of quarks and gluons kT inside colliding hadrons is ideal.

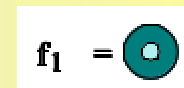
Parton Distribution Functions

A number of PDFs depends on the order of the QCD approximations.

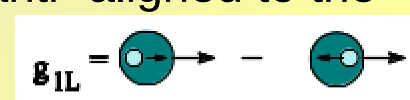
At leading order *(LO, twist-2)* 3 collinear *(integrated over kt)* PDFs are needed for a full description of the nucleon structure:



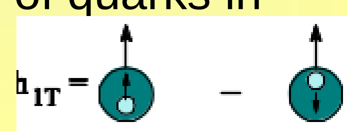
- **Density f_1 (x, Q^2)** — distribution of the parton Number/ probability to find quarks within the non-polarized (U) nucleon carrying a fraction x of the nucleon momentum



- **Helicity (chirality) g_1 (x, Q^2) ≡ g_{1L} (x, Q^2)** distribution of longitudinal polarization of quarks in longitudinally polarized (L) nucleon/ the difference in probabilities to find quarks in a longitudinally polarized nucleon with their spin aligned or anti- aligned to the spin of the nucleon



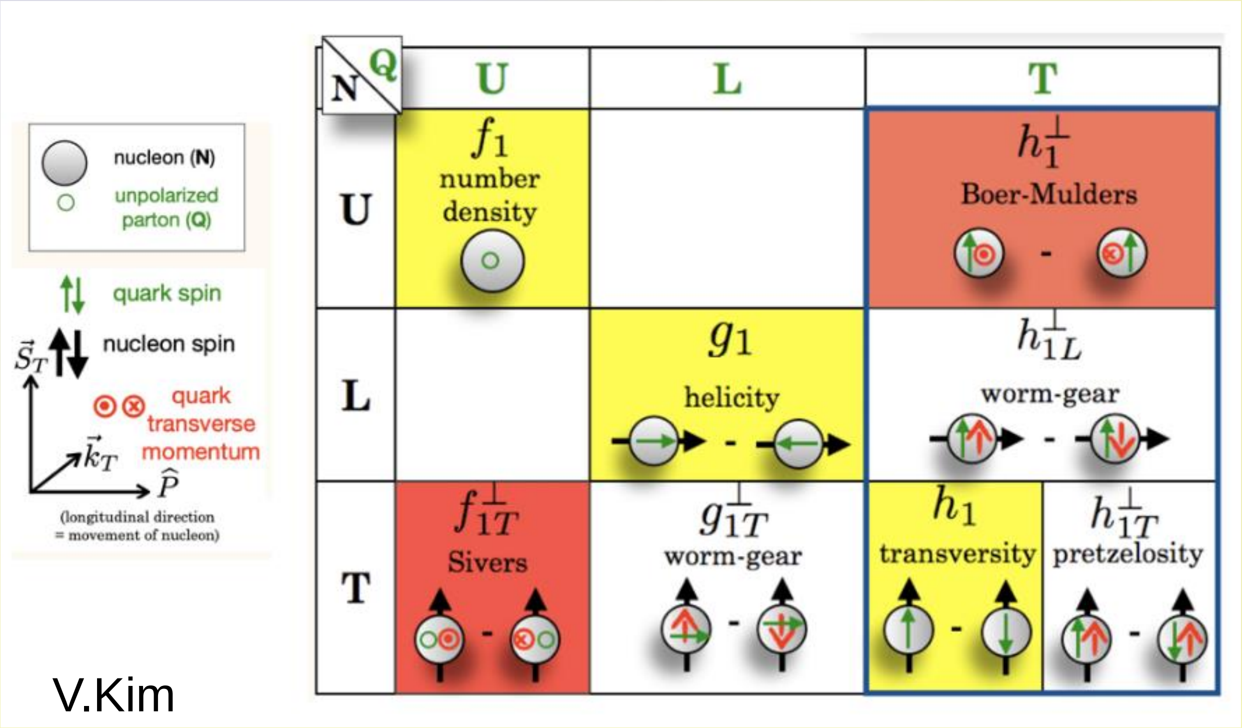
- **Transversity h_1 (x, Q^2)** - distribution of transverse polarization of quarks in transversely polarized (T) nucleon



The PDFs f_1 and g_1 are measured rather well. The PDF h_1 (x, Q^2) is poorly studied. *It was historically introduced right for DY process.*

The structure of the proton: TMD PDF

Taking into account the **quark intrinsic transverse momentum kT**, at leading order 8 TMD **(5 additional) PDFs** are needed for a full description of the nucleon structure, which are *functions of 3 variables (x, kT,Q^2)*. They are vanishes when integrating over kT.

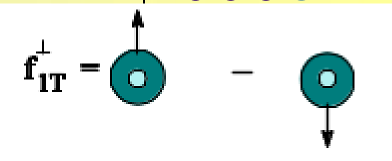


Leading twist TMD distribution functions. The **U,L,T** correspond to **u**npolarized, **l**ongitudinally polarized and **t**ransversely polarized nucleons (columns) and quarks (rows).

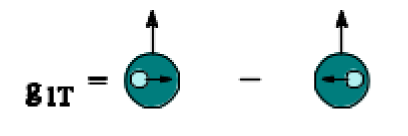
At the sub-leading twist (twist-3), there are still 16 TMD PDFs containing the information on the nucleon structure. *They have no definite physics interpretation yet.*

Since TMD distributions are nonperturbative functions, they **cannot be calculated within the framework of QCD**. Therefore, the main model-independent tool for studying TMD is **the analysis of spin effects in SIDIS and Drell-Yang processes**.

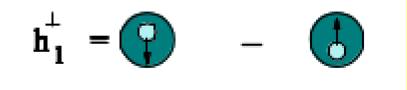
- **$f^{\perp}_{1T}$ (Sivers)** - represents the distribution over the transverse momentum of non-polarized quarks in a transversely polarized nucleon (transverse spin);



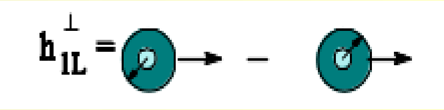
- **$g^{\perp}_{1T}$ (Worm-gear-T)** **-** correlation between the transverse spin and the longitudinal quark polarization;



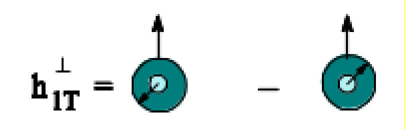
- **$h^{\perp}_{1}$ (Boer-Mulders)** - distribution over the transverse momentum of transversely polarized quarks in the non-polarized nucleon ;



- **$h^{\perp}_{1L}$ (Worm-gear-L)** **-** correlation between the longitudinal polarization of the nucleon (longitudinal spin) and the transverse momentum of quarks;



- **$h^{\perp}_{1T}$ (Pretzelosity)** **-** distribution over the transverse momentum of transversely polarized quarks in the transversely polarized nucleon.



It is very **important to measure Worm-gear-T, L and Pretzelosity** which are still not measured or measured with large uncertainties.
The last one would give new information (at least within some models) on the **possible role of constituent`s orbital momenta in the resolution of the nucleon spin crisis**.

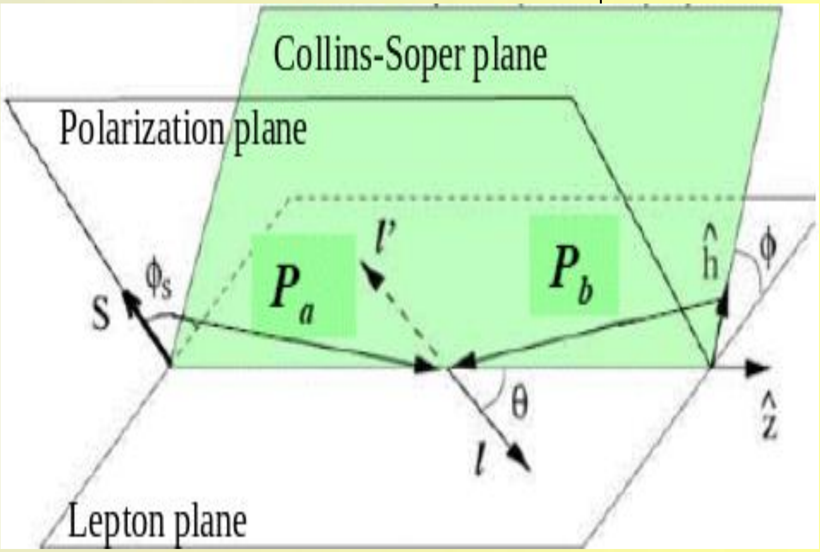
The PDFs studies via asymmetry of the DY pairs production cross sections

The **cross section** of the DY pair's production **cannot be measured directly** because there is **no single beam containing particles with the U, L and T polarization**.

To ***measure SF`s*** one can use the following procedure:

1-st - ***to integrate differential cross section over*** the azimuthal ***angle*** φ between the Lepton and Hadron planes in the Collins-Soper reference frame,

2-nd - following the SIDIS practice, ***to measure azimuthal asymmetries*** of the DY *pairs production cross sections*.



The **azimuthal asymmetries** can be **calculated** as ***ratios*** of ***cross sections differences*** to the ***sum*** of the integrated over φ ***cross sections*** $\boldsymbol{\sigma_{int}}$:

- The **numerator** of the ratio is calculated as a *difference* of the DY pair's production cross sections in the collision of hadrons h_a and h_b with *different polarizations*.
- The **denominator** of the ratio is calculated as a *sum of* σ_{int}*`s* calculated for the same hadron polarizations and same x_a, x_b regions as in numerator.

Previouse Drell-Yan experiments

Experiment	Interaction	Reaction	Energy
CERN-NA3	pN(Pt)	p Nucleus --> mu+ mu- X	Plab = 400 GeV
CERN-NA10	pi-N(W)	pi- Nucleus --> mu+ mu- X	Plab = 194, 286 GeV
CERN-NA58 (COMPASS)	pi-p	pi p → mu+ mu- X	Plab = 190 GeV
CERN-WA11	pi-N(Be)	pi- Nucleus --> mu+ mu- X	Plab = 150/175 GeV
CERN-WA39	pi+N(W) pi-N(W)	pi+ Nucleus --> mu+ mu- X, pi- Nucleus --> mu+ mu- X	Plab = 39.5 GeV
CERN-R108	pp	p p --> e+ e- X	Plab(Ecm) = 62.4 GeV
CERN-R209	pp	p p --> mu+ mu- X	Plab (sqrt(s)) = 44, 62 GeV
CERN-R808	pp	p p --> e+ e- X	Plab (sqrt(s)) = 53, 63 GeV
CERN-UA2	pbar p	pbar p --> mu+ mu- X	Plab = 630 GeV
Fermilab-E288	pN(Pt)	p Nucleus --> mu+ mu- X	Plab = 200/300/400 GeV
Fermilab-E325	pN(Cu)	p Nucleus --> mu+ mu- X	Plab = 200,300,400 GeV
Fermilab-E326	pi-N(W)	pi- Nucleus --> mu+ mu- X	Plab = 225 GeV
Fermilab-E439	pN(Cu)	p Nucleus --> mu+ mu- X	Plab = 400 GeV
Fermilab-E444	pN(C, Cu, W)	p Nucleus --> mu+ mu- X, pi+ Nucleus --> mu+ mu- X, pi- Nucleus --> mu+ mu- X	Plab = 225 GeV
Fermilab-E537	Pbar N(W), pi- N(W)	pbar p --> e+ e- X, pbar N --> mu+ mu- X, pi- Nucleus --> mu+ mu- X	Plab = 125 GeV
Fermilab-E605	pN(Cu)	p Nucleus --> mu+ mu- X	Plab = 800 GeV
Fermilab-E615	pi- N(W)	pi- Nucleus --> mu+ mu- X	Plab = 252 GeV
Fermilab-E740(D0)	pbar p	pbar p --> e+ e- X	Ecms (sqrt(s)) = 1800 GeV
Fermilab-E741(CDF)	pbar p	pbar p --> mu+ mu- X , pbar p --> e+ e- X	Ecms (sqrt(s)) = 1800 GeV
Fermilab-E772	pp	p p --> mu+ mu- X	Plab = 800 GeV
Fermilab-E866(NUSEA)	pp	p p --> mu+ mu- X	Plab = 800 GeV

Experiments studying nucleon spin structure

experiment	CERN, COMPASS-II	FAIR, PANDA	FNAL, E-906	RHIC, STAR	RHIC-PHENIX	NICA, SPD
mode	Fixed Target	Fixed T.	Fixed T.	collider	collider	collider
Beam/target	π- , p	anti-p, p	π- , p	pp	pp	pp, pd,dd
Polarization:b/t	0; 0.8	0; 0	0; 0	0.5	0.5	0.9
Luminosity	$2 \cdot 10^{33}$	$2 \cdot 10^{32}$	$3.5 \cdot 10^{35}$	$5 \cdot 10^{32}$	$5 \cdot 10^{32}$	10^{32}
√s , GeV	19	<5.5	16	200, 500	200, 500	10 - 26
$x_{1(beam)}$ range	0.1-0.9	0.1-0.8	0.1-0.5	0.03-1.0	0.03-1.0	0.1-0.8
q_T, GeV	0.5 -4.0	0.5 -1.5	0.5 -3.0	1.0 -10.0	1.0 -10.0	0.5 -6.0
Lepton pairs,	μ-μ+	μ-μ+	μ-μ+	μ-μ+	μ-μ+	μ-μ+, e+e-
Data taking	2015	>2025	2013	>2016	>2016	>2020
Transversity	NO	NO (?)	NO	YES	YES	YES
Boer-Mulders	YES	YES	YES	YES	YES	YES
Sivers	YES	YES (?)	YES	YES	YES	YES
Pretzelosity	NO	NO	NO	NO	YES	YES
Worm Gear	NO	NO	NO	NO	NO	YES

arXiv:1408.3959, 2014

The tests at the SPD would have a number of advantages for DY measurements related to the nucleon structure studies:

- **Running with pp, pd and dd beams,**
- **Scan of the effects over a *range of beam energies*,**
- **Running with non-polarized, transverse and longitudinally polarized beams and their combinations.**

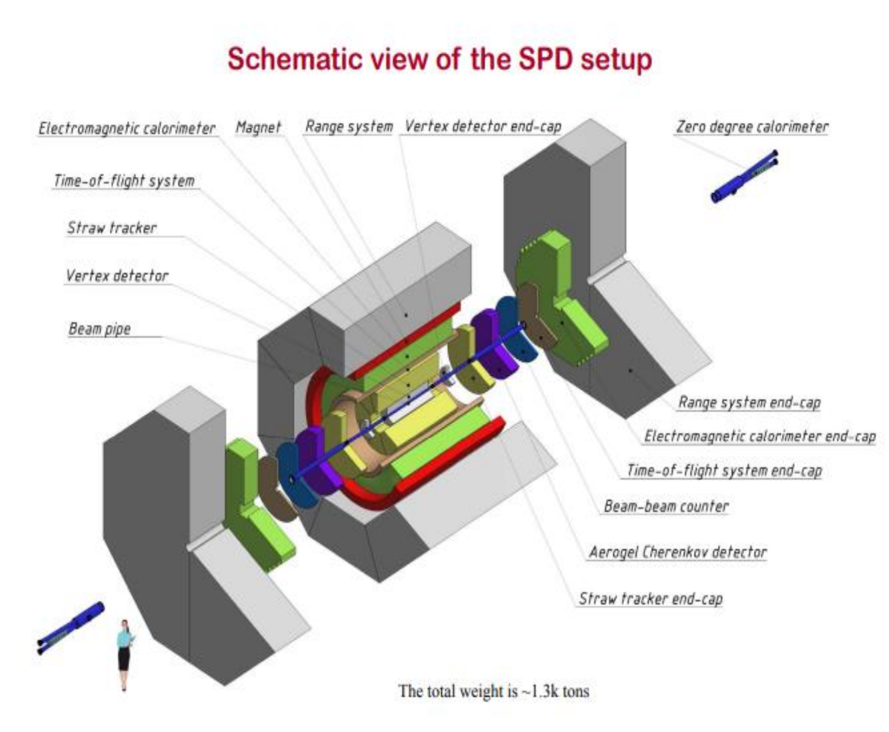
The above advantages would permit, for the first time, to perform comprehensive studies of **all leading twist PDFs** of the nucleon in a **single experiment** with minimal systematic errors.

SPD — Spin Physics Detector

Beam energies:

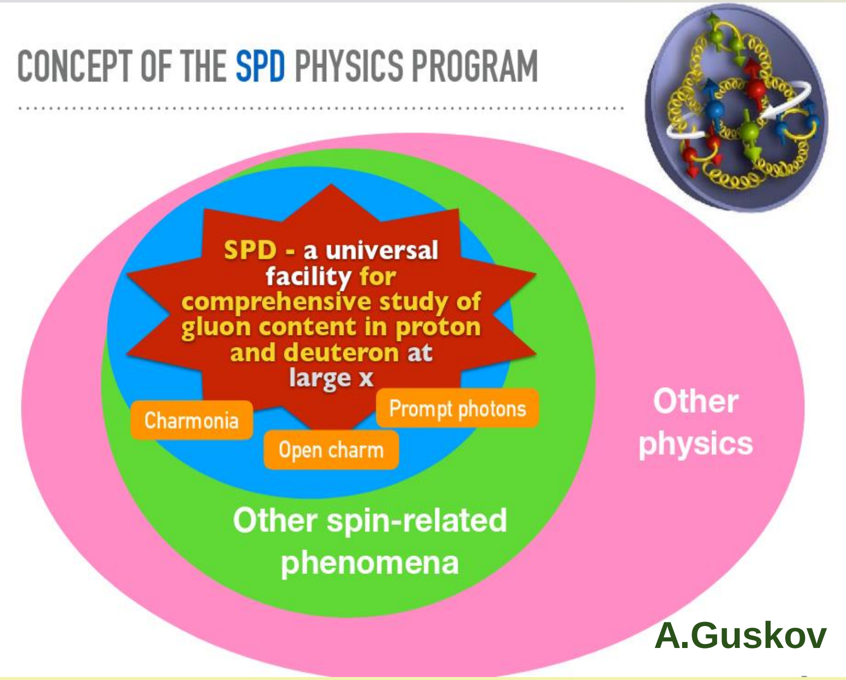
p↑-p↑($\sqrt{s_{pp}}$) = 12 ÷27 GeV (5 ÷12.6 GeV of proton kinetic energy),
d↑-d↑($\sqrt{s_{NN}}$) = 4 ÷13.5 GeV (2 ÷5.9 GeV/u of ion kinetic energy),
p↑-d↑($\sqrt{s_{NN}}$) ≤ 19 GeV

- **Luminosity up to $1 \cdot 10^{32}$ cm^{-2}s^{-1} (p-p)**
- **$0.25 \cdot 10^{32}$ cm^{-2}s^{-1} (d-d)**
- Universal 4π detector with advanced tracking and particle identification capabilities based on modern technologies.
- Capability to detect events with high collision rate (up to 4MHz)
- Tracking : ~<100 μm vertex resolution
- Photon detection with the energy resolution ~ 5%/√E
- Transverse momentum resolution $\sigma_{pT}/pT \approx 2\%$



SPD Physics Program

The Spin Physics Detector (SPD) project aims to investigate the nucleon spin structure and polarization phenomena in polarized p-p and d-d collisions.



«Possible studies at the first stage of the NICA collider operation with polarized and unpolarized proton and deuteron beams» **arXiv:2102.08477**, 2021

«On the physics potential to study the gluon content of proton and deuteron at NICA SPD» **arXiv:2011.15005**, 2021

The plans to study Drell-Yan (DY) at SPD initially were the first in the list of physics proposal at SPD facility

«Spin Physics Experiments at NICA-SPD with polarized proton and deutron beams>.
LoI **arXiv:1408.3959**,2014

V.A. Matveev, R.M. Muradian, A.N. Tavkhelidze (MMT)

(V.A. Matveev, R.M. Muradian, A.N Tavkhelidze, JINR-P2-4543, JINR, Dubna, 1969; SLAC-TRANS-0098)

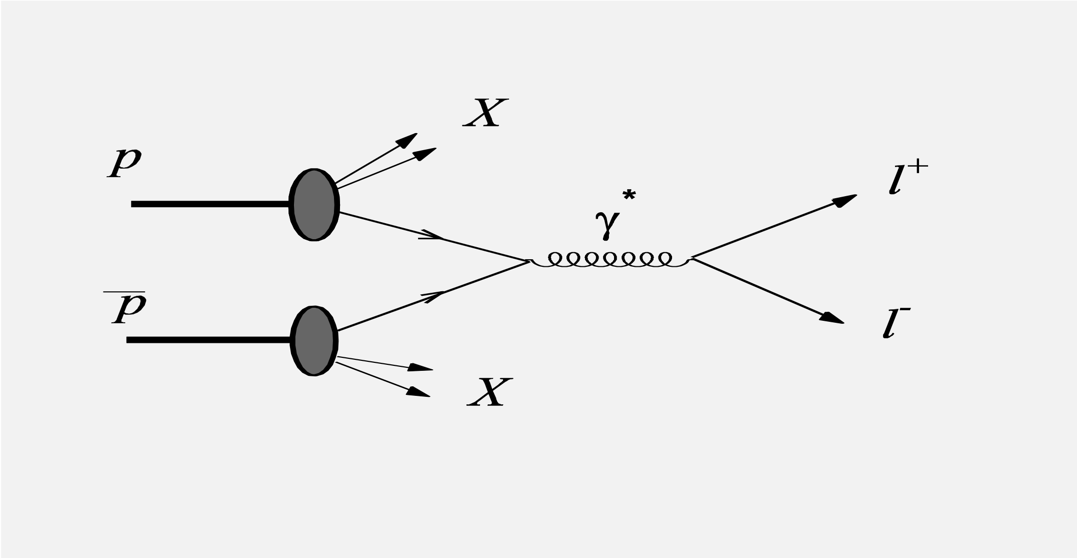
process, called also as Drell-Yan

(S.D. Drell, T.M. Yan, SLAC-PUB-0755, Jun 1970,12p.; Phys.Rev.Lett. 25(1970)316-320, 1970)

The dominant mechanism of the $\ell^+\ell^-$ production is the perturbative QED/QCD partonic 2 → 2 process

$\bar{q}q \to \gamma^* / Z^\circ \to \ell^+\ell^-$

$\sigma = 9.6 * 10^3$ pb



PYTHIA 6.4 simulation for the $E_{(p\text{-}p\ cms)} = 27$ GeV

For the Luminosity $L = 1 \times 10^{32}\ cm^{-2}s^{-1}$ with assumption of 10^7 sec/year of beam operation we expect up to 9.5×10^6 Drell-Yan events/year (without any cuts) & ~79 700 Drell-Yan events/year for $M_{inv}(\mu^+\mu^-) > 4$ GeV (and first 2 cuts)

Main backgrounds

Main contribution to backgrounds for $\bar{q}\, q \rightarrow \gamma^* \rightarrow \mu^+\mu^-$ process comes from two sources:
QCD (+charmonium) **and Minimun-bias events**

Initial conditions for simulation (both signal and BKG) are:
ISR, FSR, MPI – ON ; Lund fragmentation

We allow particles decay (and produce muons) in the volume before the Muon (Range) System :
cylindr radius R = 2 400 mm / size from the centre along Z axis L = 4 000 mm
and search for muons in the angle region $3^o < \Theta < 177^o$

Contribution from b-quarks *(subprocesses 81, 82, 461- 479)* **is negligible**.
Total cross-section is **0.34×10^{-6} mb**. Initial **S/B ≃ 27**.

Contribution from charmonia *(subprocesses 86, 87-89, 104-105, 106, 421-439)*
is less than from QCD and Mini-bias, but significant.
Their cross-section is **8.6×10^{-4} mb**. Initial **S/B = 1.0×10^{-2}.**

Contribution from Charm production *(subprocesses 81. q + qbar --> c cbar*
82. q + g --> c cbar)
Total cross-section is **1.9×10^{-3} mb**. Initial **S/B ≃ 5.2×10^{-3}**

{Easy to suppress}

Main backgrounds

Now they are included in the **total list of QCD events** modeling
(subprocesses 10-14, 28-29, 53, 68)

The main contributions come from the following partonic subprocesses:

q + g → q + g (gives 43.5**%** of QCD events with the **σ** = **92.7** mb);

g + g → g + g (gives 46.7**%** of QCD events with the **σ** = **99.5** mb);

q + q' → q + q' (gives 9.2**%** of QCD events with the **σ** = **19.7** mb);

For QCD background σ = 212.9 mb, S/B ≃ 4.6 x 10^{-8}

(one order stronger than Mini-bias!)

Minimum-Bias processes

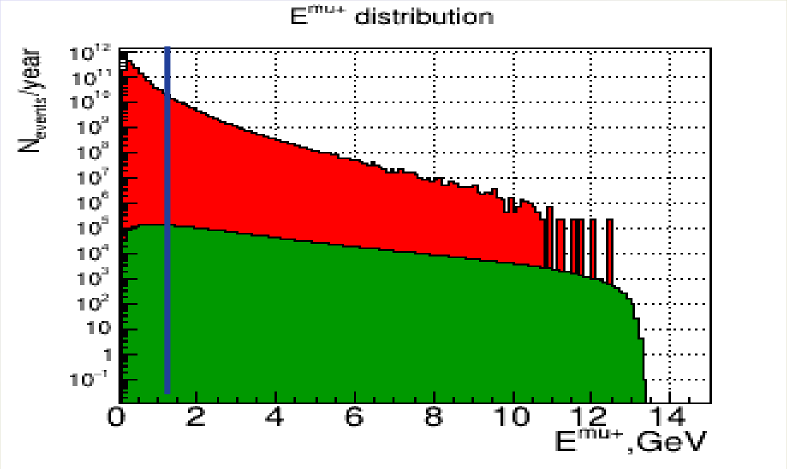
95. Low - PT scattering (~65**%** of MB events with the **σ** = **14.0** mb);

92-93. Single diffractive (24.8**%** of MB events with the **σ** = **7.35** mb);

94. Double diffractive (7.2**%** of MB events with the **σ** = **2.12** mb);

σ = 23.7 mb. S/B ≃ 4.2 x 10^{-7}

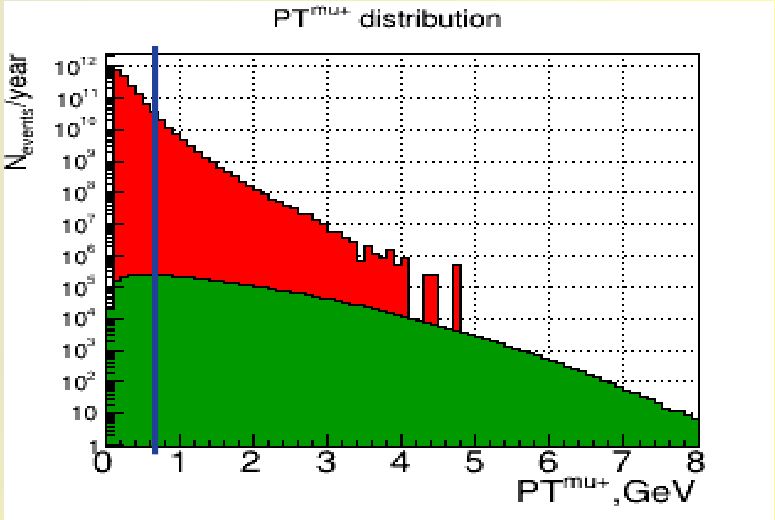
First cuts - on E(P) and PT

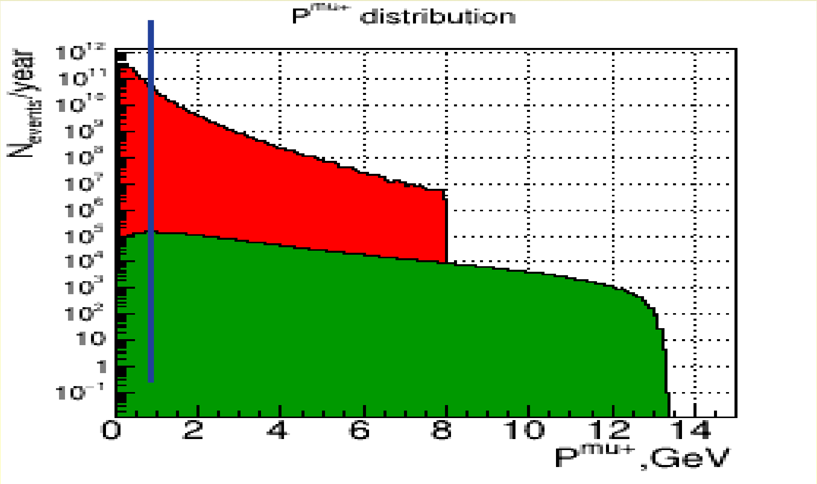


Effective cut off on E(P) only in the region

$E^{\mu}_{bkg} < 1.5$ GeV ***(example $E^{\mu}_{bkg} = 1.0$ GeV)***

where is the maximum gradient in E^{μ}_{bkg} distribution





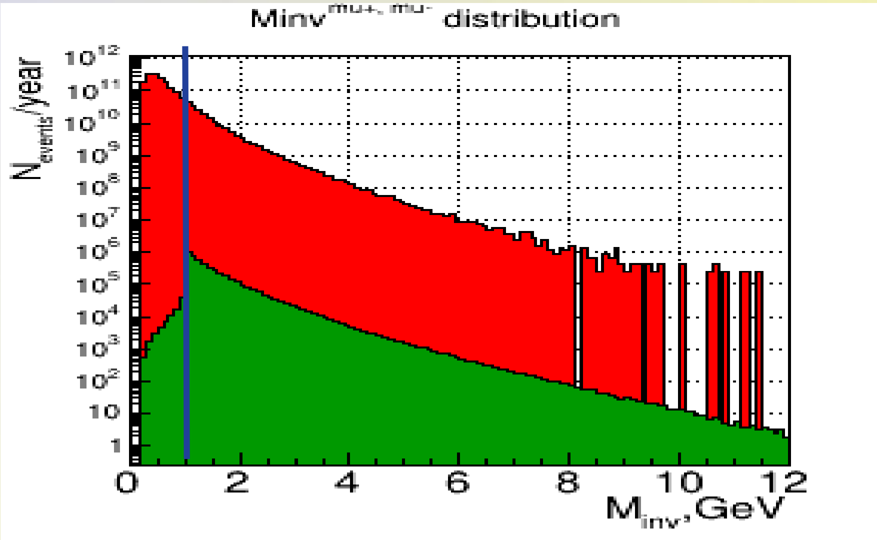
The most effective cuts off are in the region

$PT^{\mu}_{bkg} < 1.5$ GeV

(for example $PT^{\mu}_{bkg} = 0.6$ GeV)

Invariant mass cut

(picture corresponds to minimum-bias backgrounds)



The most effective cut is in the region **~ 1 GeV.**

Further increase of Minv cut has no sense for Minimum-bias background events (it leads to significant loss of signal events without real improvement of S/B ratio) except backgrounds in the regions of J/Ψ and other resonances production.

Efficiency of M_{inv} (μ^+,μ^-) cut

Together with the cut on $E(P)^{\mu}$ > 1 GeV, PT^{μ} > 0.6 GeV and opposite sign leptons

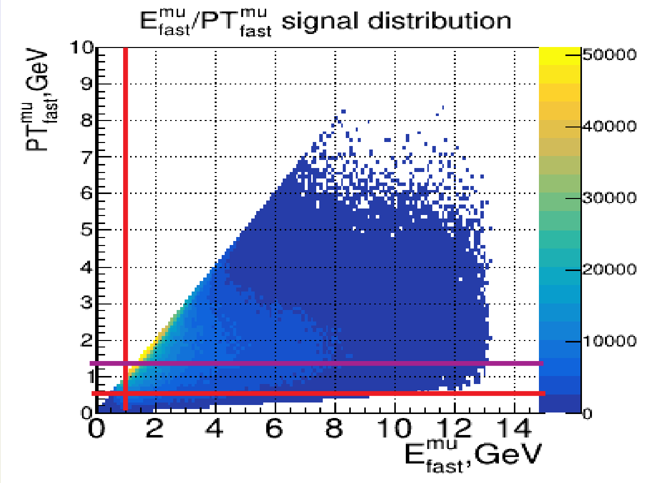
Cut efficiency = Nev(cutN) / Nev(init)

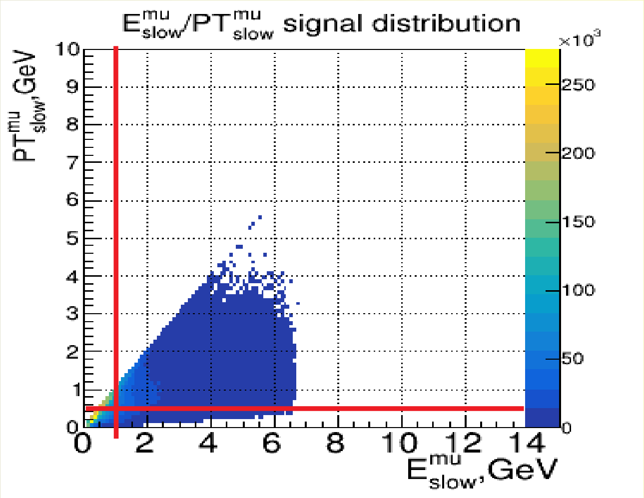
Minv cut	Rest of BKG	Cut efficiency for BKG	Rest of SIG	Rest of SIG events/year	Cut efficiency for SIG	S/B
$M^{\mu\mu}_{inv}$ > 1.0 GeV	1.70 x 10^{-2} %	1.36	**40.5 %**	**3 869 571**	1.02	**1.0 x 10^{-4} %**
$M^{\mu\mu}_{inv}$ > 1.5 GeV	1.35 x 10 ^{2} %	1.69	16.7 %	1 595 601	2.97	6.3 x 10^{-5} %
$M^{\mu\mu}_{inv}$ > 2.0 GeV	9.57 x 10^{-3} %	2.41	8.3 %	793 023	7.28	4.4 x 10^{-5} %
$M^{\mu\mu}_{inv}$ > 2.5 GeV	6.05 x 10^{-3} %	3.80	4.5 %	429 952	15.9	3.8 x 10^{-5} %
$M^{\mu\mu}_{inv}$ > 3.0 GeV	3.70 x 10^{-3} %	6.22	2.5 %	238 862	32.0	3.4 x 10^{-5}%
$M^{\mu\mu}_{inv}$ > 3.5 GeV	2.24 x 10^{-3} %	10.3	1.4 %	133 762	60.7	3.2 x 10^{-5} %
$M^{\mu\mu}_{inv}$ > 4.0 GeV	1.38 x 10^{-3} %	16.7	**0.8 %**	**76 435**	110.1	**2.9 x 10^{-5} %**
$M^{\mu\mu}_{inv}$ > 4.5 GeV	8.49 x 10^{-4}%	27.1	0.5 %	47 772	192.2	3.0 x 10^{-5} %
$M^{\mu\mu}_{inv}$ > 5.0 GeV	5.28 x 10^{-4} %	43.7	0.3 %	28 663	328.0	2.9 x 10^{-5} %

Minv cut doesn"t influence much on S/B ratio. But at **$M^{\mu\mu}_{inv}$ > 4.0 GeV** we have **too small number of events/year.**

E^{μ}/PT^{μ} correlations for muons with max(fast) / min(slow) E^{μ} in the pair

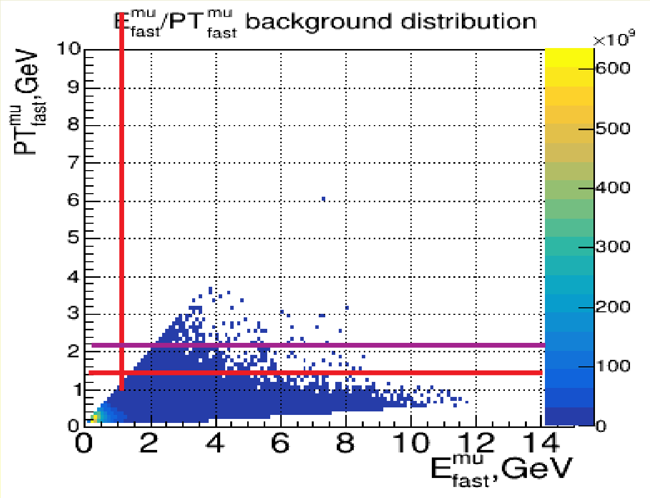
S I G

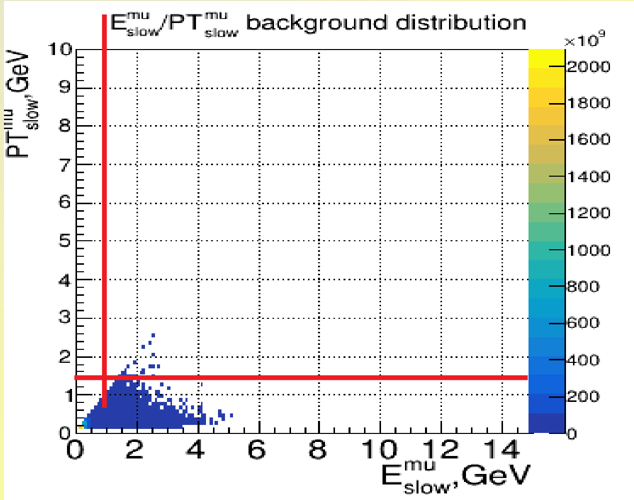




$PT^{\mu}_{fast} > 1.5$ GeV

B K G

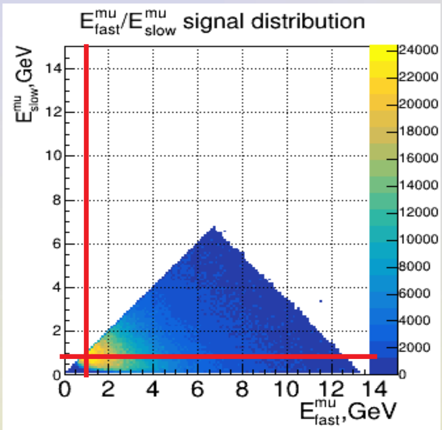


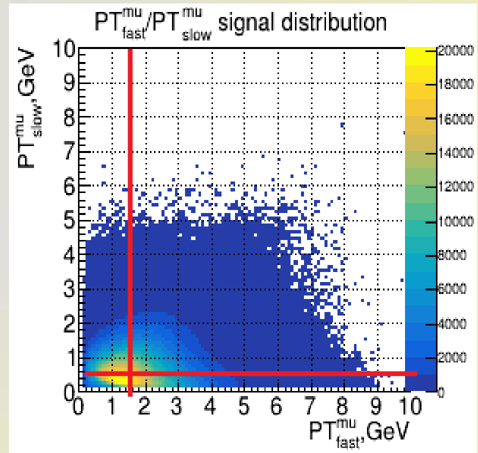


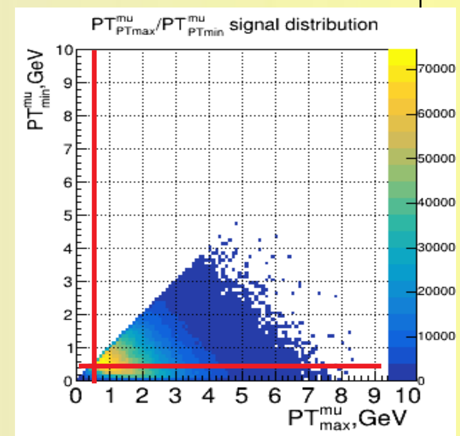
Cut on $PT^{\mu} > 0.6$ GeV and $E^{\mu} > 1.0$ GeV

E^{μ}_{max}(fast) /E^{μ}_{min}(slow), $PT^{\mu}_{fast}/PT^{\mu}_{slow}$, $PT^{\mu}_{max}/PT^{\mu}_{min}$ distributions

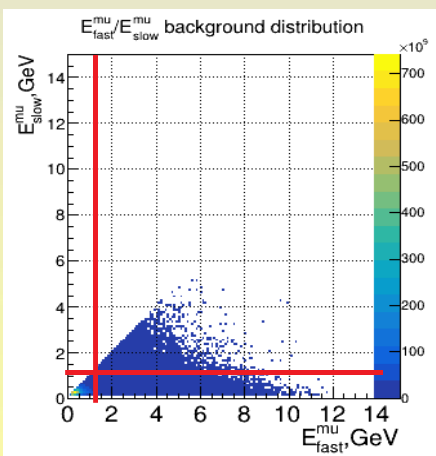
S I G

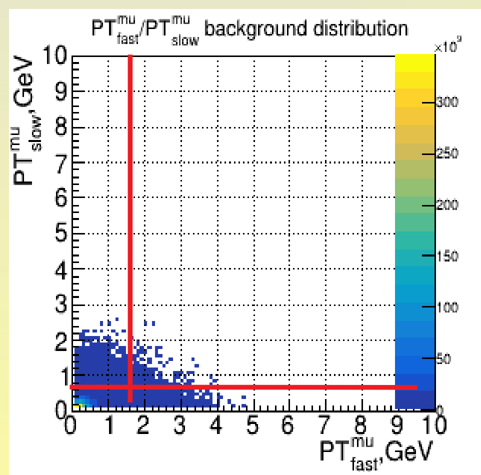


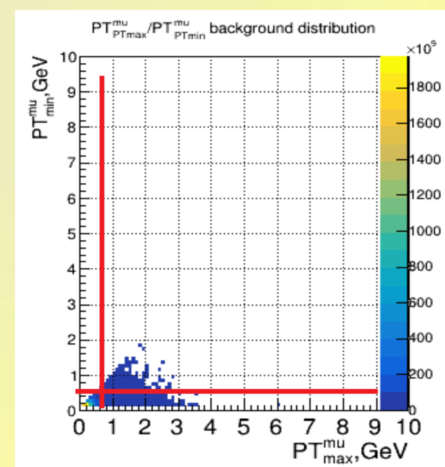




B K G





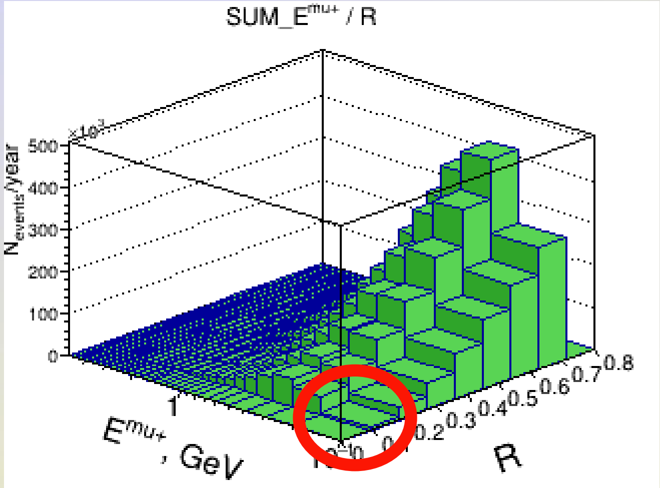


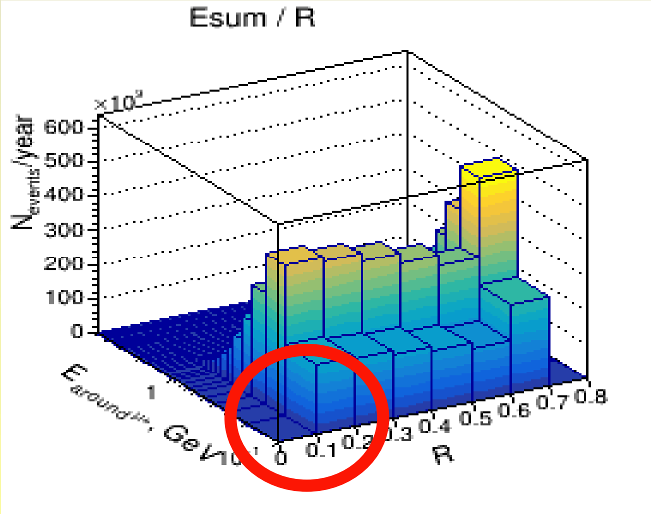
E^{μ} > 1.0 GeV

PT^{μ}_{fast} > 1.5 GeV

PT^{μ} > 0.6 GeV

Lepton (μ) isolation criteria





The plots show the distributions over ***summarized energy*** of the final state charged particles in the cones of radius **$R_{isolation} = \sqrt{\Delta\eta^2+\Delta\varphi^2}$** respect to the the
(η – pseudorapidity, φ — azimuthal angle)

upper plot **signal events**

bottom plot **Mini-bias background**

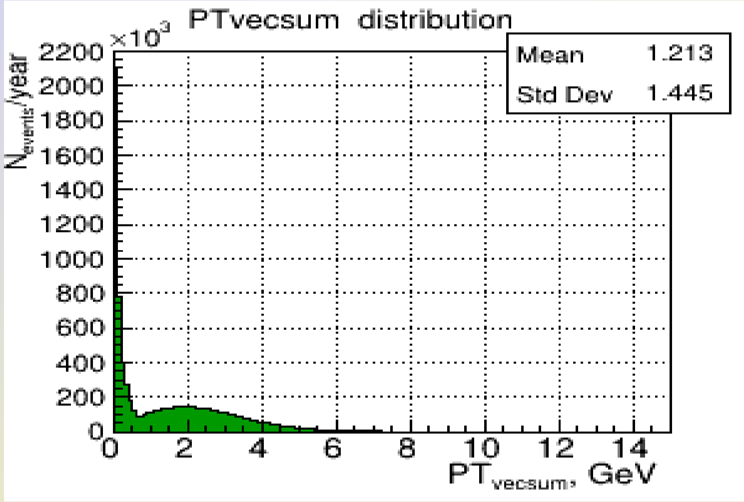
Isolation criteria **($R_{isolation} = 0.2$)**
E_{sum} (of particles) < 0.5 GeV

allows to separate most part
of Mini-bias & QCD bkg muons
with additional loss of **0.7%** of signal events

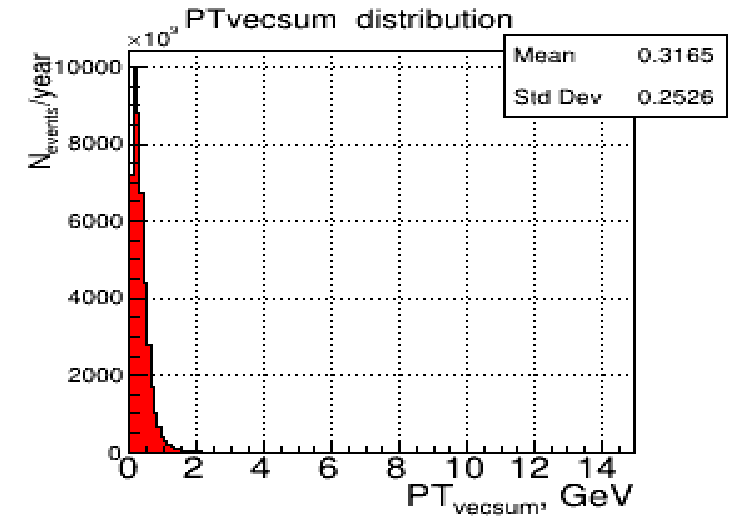
after applied cuts discussed above

Cut on PT_{vecsum} - vector sum of all particles transverse momenta in event

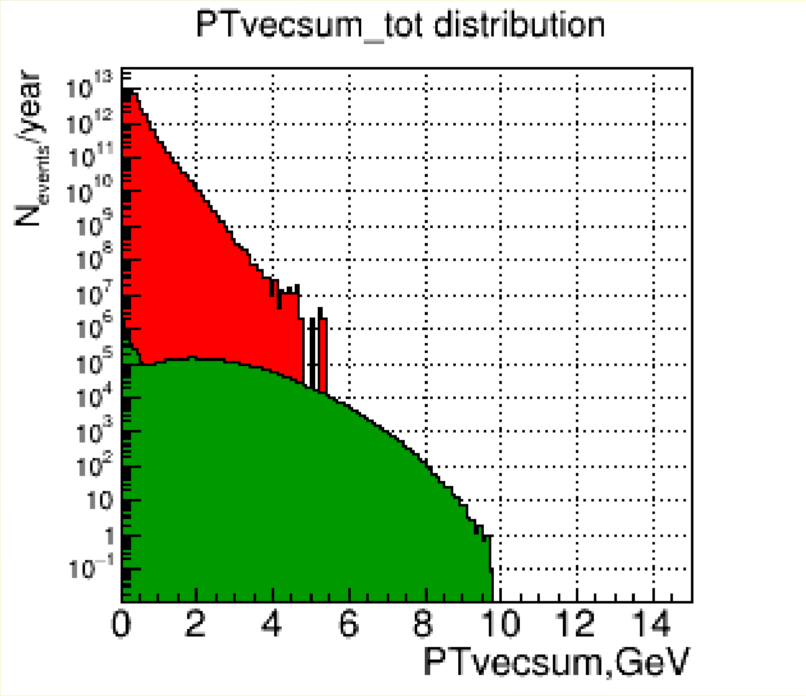
S I G



B K G



Sig & BKG
in log scale

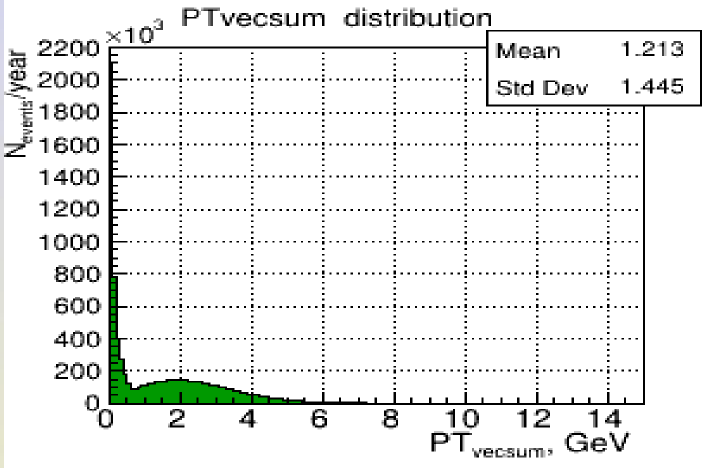


PT_{vecsum} < 0.2 GeV

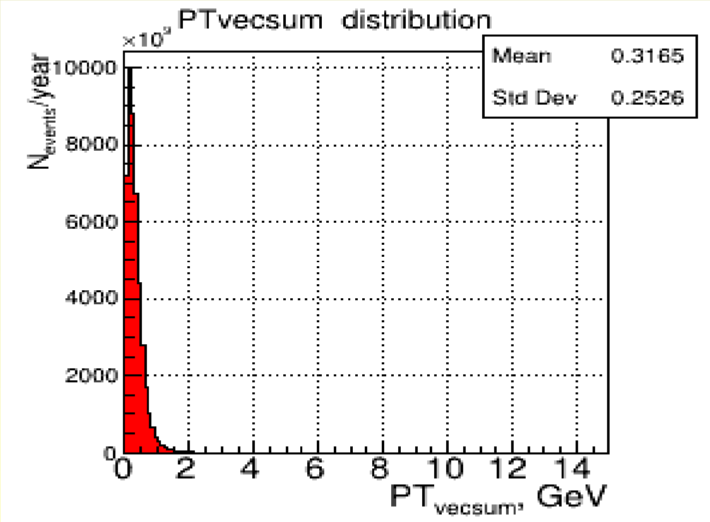
BKG suppression factor (Eff) = 4

Analogous cut on P_{vecsum} - vector sum of all particles momenta in event

S I G

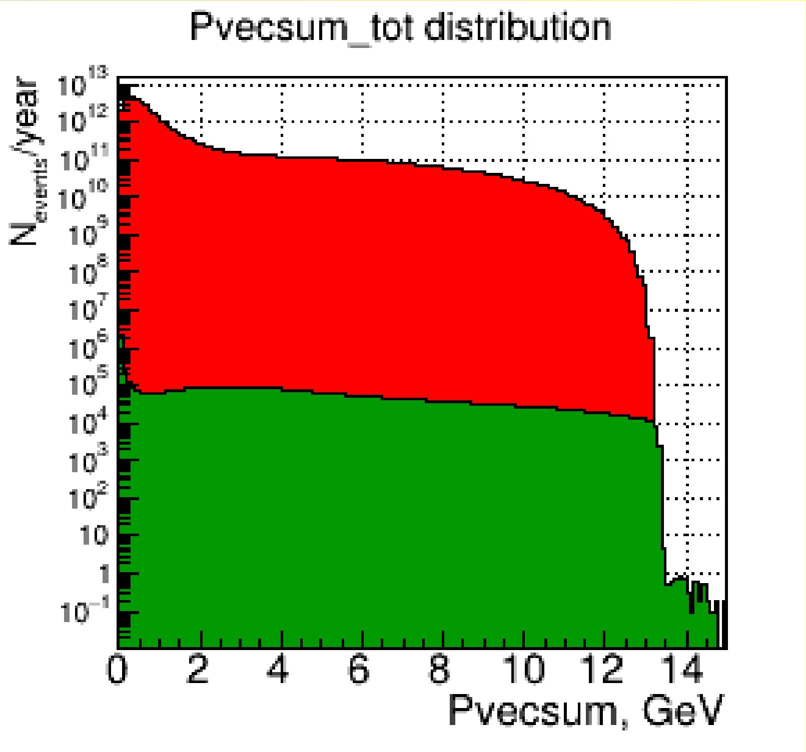


B K G



Sig & BKG

in log scale

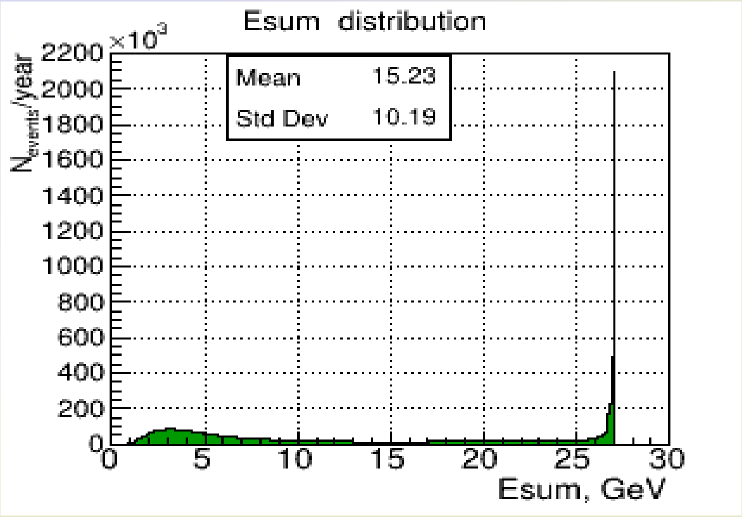


P_{vecsum} < 0.2 GeV

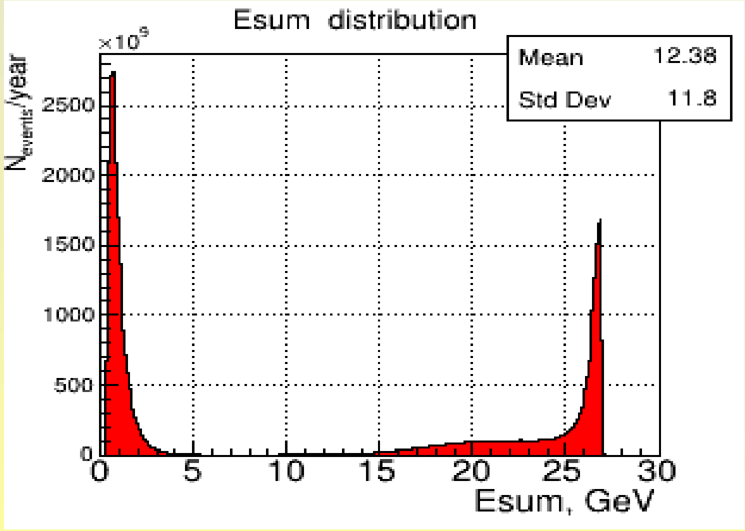
BKG suppression factor (Eff)= 18 - 19

Cut on E_{sum} - summarized energy of all detected particles in event

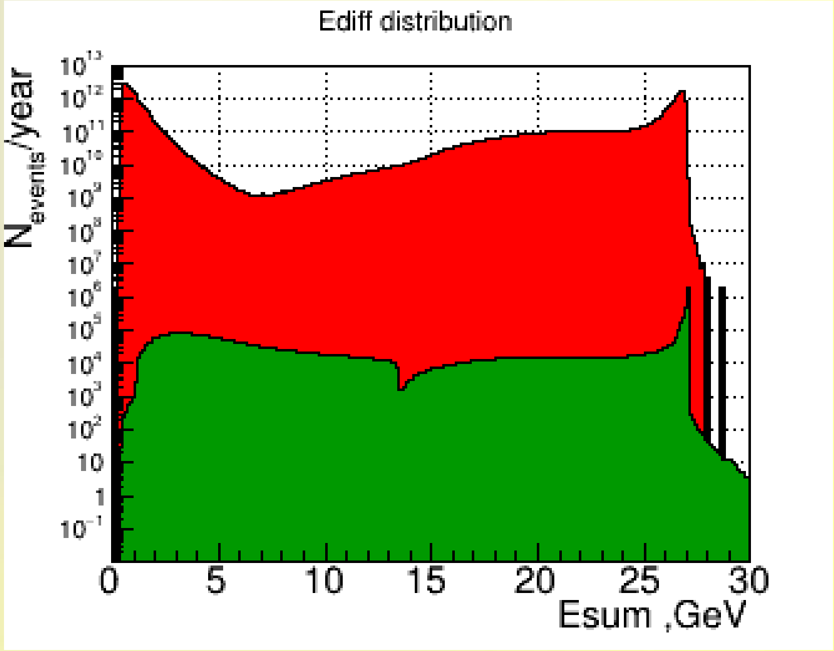
S I G



B K G



Sig & BKG
in log scale



E_{sum} > 26.8 GeV

BKG suppression factor (Eff) = 58 (MB) – 67 (QCD)

Proposed cuts

1. Events with only 2 muons with **$PT^{\mu} > 0.6$ GeV, $E^{\mu} > 1.0$ GeV**
2. Muons are of the **opposite sign**
3. **M_{inv} $(\mu^{+}, \mu^{-}) > 1.0$ GeV**
4. **$PT^{\mu}_{fast} > 1.5$ GeV**
5. The vertex of production placed within the **distance** from the interaction point $R < 1(30)$ mm

   But! Fit program can misidentify **μ** and **π** as one track due to small angle of **π->μ (+ν)** decay .
6. Cut on summarized energy of all detected (without pipe zone and neutrino) particles in event **$E_{sum} > 26.8$ GeV**
7. Isolation criterion **$E^{sum}_{(R\ isolation\ =\ 0.2)} < 0.5$ GeV**

Cuts separate and summarized efficiency for Minimun-bias background events (10^9)

Efficiency Eff (K,N) = Nev(cutN) / Nev(cutK)

N of cuts	S/B ratio	*Efficiency for BKG*	Rest of BKG	*Efficiency for SIG*	Rest of SIG
1 *Exactly 2μ* with $PT^{\mu} > 0.6$ GeV, $P(E)^{\mu} > 1.0$ GeV	$5.1 * 10^{-4}$	Eff (1,init) = **3480**	2.9×10^{-2} %	2.3	44.1 %
2^{+1} *2μ are of the opposite sign*	$8.9 * 10^{-4}$	Eff (2,1) = **1.8**	1.6×10^{-2} %	1.01	43.8 %
3^{+2+1} M_{inv} (μ+,μ-) > 1.0 GeV	$1.2 * 10^{-3}$	Eff (3,2) = **1.3**	1.2×10^{-2} %	1.01	43.8 %
4^{+3+2+1} $PT^{\mu}_{Emax} > 1.5$ GeV	$1.1 * 10^{-2}$	Eff (4,3) = **13.2**	9.1×10^{-4} %	1.43	30.5 %
5^{+3+2+1} $E^{all}_{sum} > 26.8$ GeV	$2.6 * 10^{-2}$	Eff (5,3) = **58.3**	2.1×10^{-4} %	2.63	16.6 %
6^{+3+2+1} $PT^{all}_{vecsum} < 0.2$ GeV	$2.9 * 10^{-3}$	Eff (6,3) = **4.1**	2.9×10^{-3} %	1.70	25.7 %
7^{+3+2+1} $P^{all}_{vecsum} < 0.2$ GeV	$9.4 * 10^{-3}$	Eff (7,3) = **18.4**	6.5×10^{-4} %	2.34	18.7 %
8^{+3+2+1} *Isolation criterium*	47.6	Eff (8,3) **= 30177**	4.0×10^{-7} %	1.01	**43.2 %**
9^{+3+2+1} $R_{vertex} < 1$ mm	$8.5 * 10^{-1}$	Eff (9,3) = **710**	1.7×10^{-5} %	1.01	43.5 %
10^{+3+2+1} $R_{vertex} < 30$ mm	$7.1 * 10^{-1}$	Eff (10,3) = **597**	2.0×10^{-5} %	1.01	43.5 %
$5^{+4+3+2+1}$ $E^{all}_{sum} > 26.8$ GeV	$2.3 * 10^{-1}$	Eff (5,4) = **52.7**	1.7×10^{-5} %	2.52	12.1 %
$8^{+4+3+2+1}$ Isolation criterium	24.7	Eff (8,4) = **2280**	4.0×10^{-7} %	1.02	**29.9 %**
$8^{+5+4+3+2+1}$ Isolation criterium	> 54	Eff (8,5) > **173**	$< 1.0 \times 10^{-7}$ %	1.87	**16.3 %**

Cuts separate and summarized efficiency for QCD (+charmonia) background events (10^9)

Efficiency Eff (K,N) = Nev(cutN) / Nev(cutK)

N of cuts	S/B ratio	*Efficiency for BKG*	Rest of BKG	*Efficiency for SIG*	Rest of SIG
1 *Exactly 2μ* with $PT^{\mu} > 0.6$ GeV, $P(E)^{\mu} > 1.0$ GeV	$4.4 * 10^{-5}$	Eff (1,init) = **2471**	4.0×10^{-2} %	2.8	35.3 %
2^{+1} *2μ are of the opposite sign*	$7.4 * 10^{-5}$	Eff (2,1) = **1.7**	2.3×10^{-2} %	1.2	33.3 %
3^{+2+1} *M_{inv} (μ+,μ-) > 1.0 GeV*	$1.0 * 10^{-4}$	Eff (3,2) = **1.3**	1.7×10^{-2} %	1.0	33.3 %
4^{+3+2+1} *$PT^{\mu}_{Emax} > 1.5$ GeV*	$7.4 * 10^{-4}$	Eff (4,3) = **14.1**	1.2×10^{-3} %	1.9	17.6 %
5^{+3+2+1} *$E^{all}_{sum} > 26.8$ GeV*	$2.4 * 10^{-3}$	Eff (5,3) = **67.4**	2.5×10^{-4} %	2.8	11.7%
6^{+3+2+1} *$PT^{all}_{vecsum} < 0.2$ GeV*	$2.5 * 10^{-4}$	Eff (6,3) = **4.2**	4.0×10^{-3} %	1.7	19.6 %
7^{+3+2+1} *$P^{all}_{vecsum} < 0.2$ GeV*	$9.3 * 10^{-4}$	Eff (7,3) = **19.7**	8.6×10^{-4} %	2.2	15.7 %
8^{+3+2+1} *Isolation criterium*	> 17	Eff (8,3) **> 169847**	< 1.0×10^{-7} %	1.0	**33.3 %**
9^{+3+2+1} *$R_{vertex} < 1$ mm*	$5.5 * 10^{-2}$	Eff (9,3) = **551**	3.0×10^{-5} %	1.0	33.3 %
10^{+3+2+1} *$R_{vertex} < 30$ mm*	$4.8 * 10^{-2}$	Eff (10,3) = **479**	3.5×10^{-5} %	1.0	33.3 %
$5^{+4+3+2+1}$ *E^{all}_{sum}* > 26.8 GeV	$1.6 * 10^{-2}$	Eff (5,4) = **64.5**	1.8×10^{-5} %	3.0	5.9 %
$8^{+4+3+2+1}$ Isolation criterium	> 9	Eff (8,4) **> 12066**	< 1.0×10^{-7} %	1.0	**17.6 %**
$8^{+5+4+3+2+1}$ Isolation criterium	> 3	Eff (8,5) > **187**	< 1.0×10^{-7} %	1.0	**5.9 %**

Conclusion

The proposed cuts:

1. Events with only 2 muons with **$PT^{\mu} > 0.6$ GeV, $E^{\mu} > 1.0$ GeV**
2. Muons are of the **opposite sign**
3. **$M_{inv}(\mu^{+}, \mu^{-}) > 1.0$ GeV**
4. **$PT^{\mu}_{fast} > 1.5$ GeV**
5. Cut on summarized energy of all detected (without pipe zone and neutrino) particles in event **$E_{sum} > 26.8$ GeV**
6. Isolation criterion **$E^{sum}_{(R\ isolation\ =\ 0.2)} < 0.5$ GeV**

Allow (in the ideal case) to suppress Mini-bias bkgd up to ***S/B ~ 50****, QCD background – up to* ***S/B >~ 17.***

The SPD Collaboration made a decision to suspend the study of such reactions.

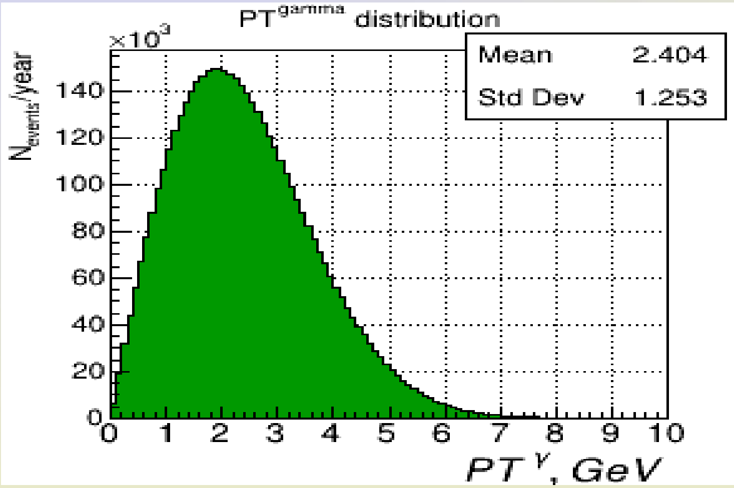
In fact, taking into account the detector and additional contributions of muon misidentification,
it will be difficult to experimentally isolate the DY signal from the combinatorial background.

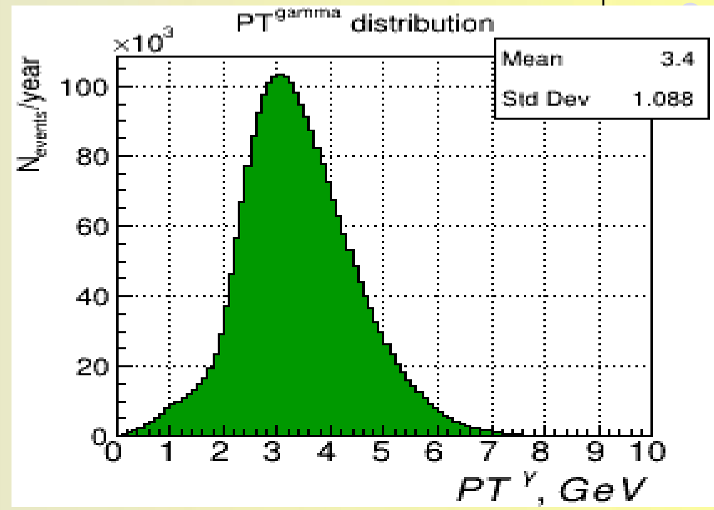
Thank you for your attention!

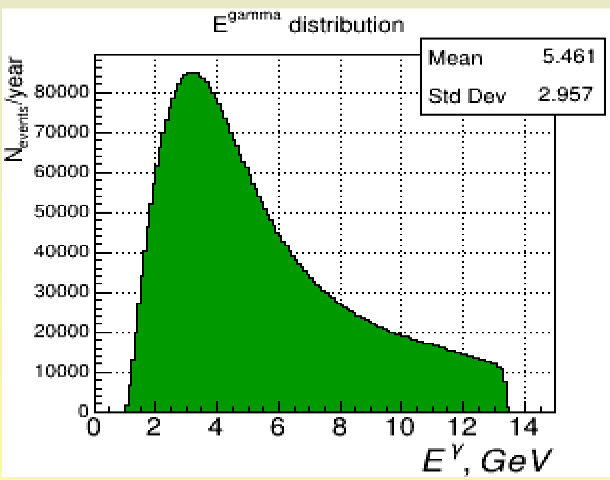
Back up slides

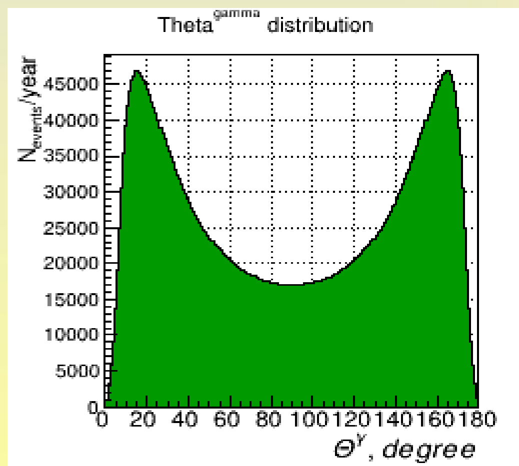
Intermediate γ^* distributions

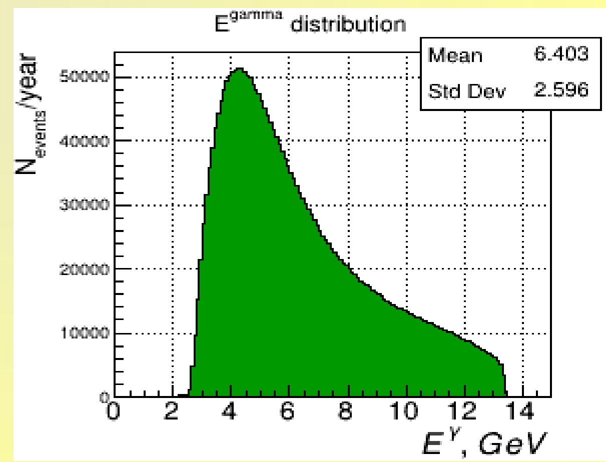
Without cuts ***After cuts***





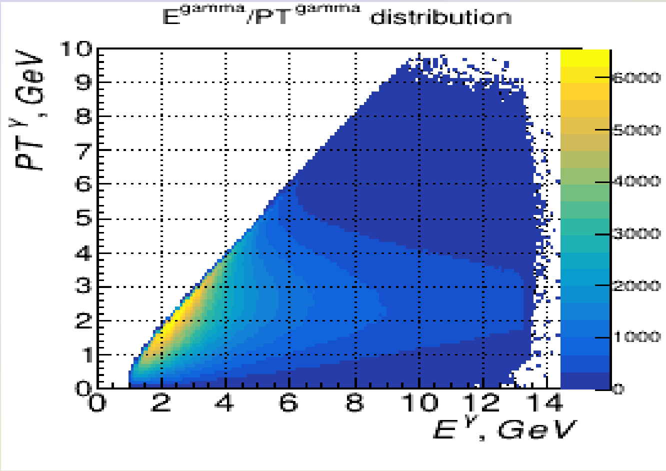




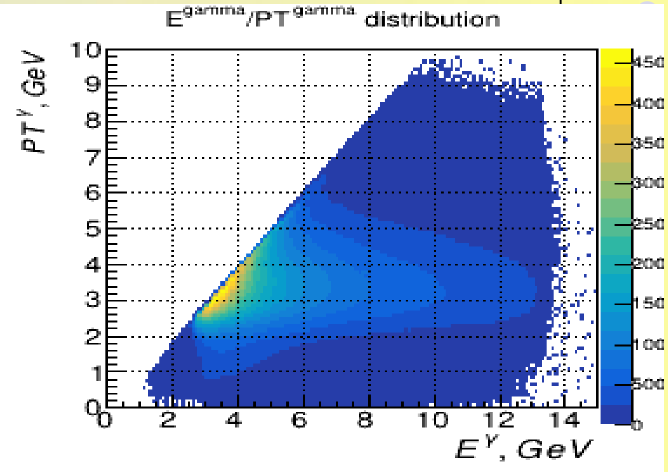


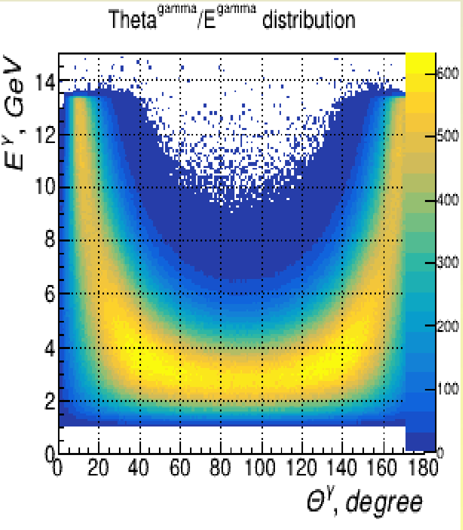
Intermediate γ* correlation distributions

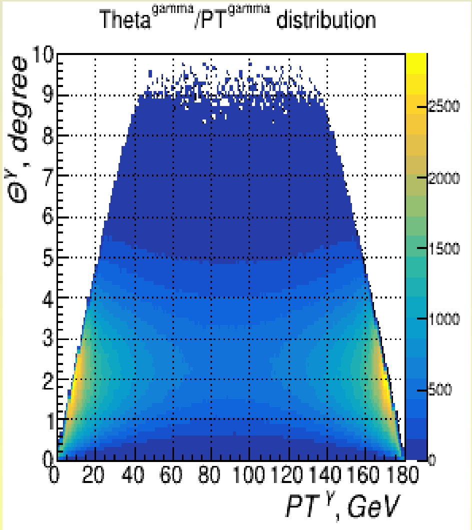
Without cuts

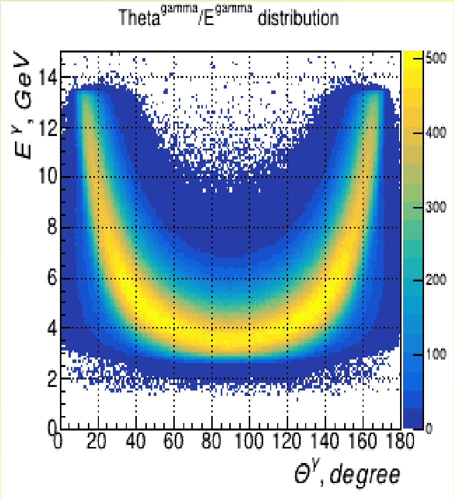


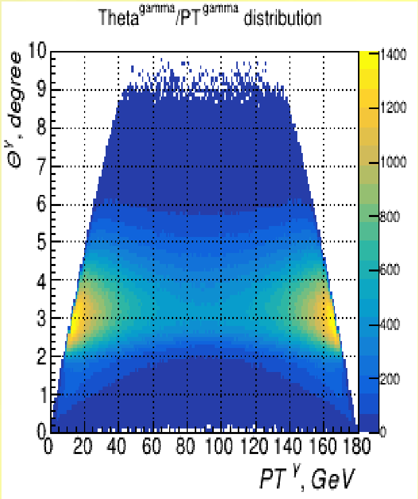
After cuts





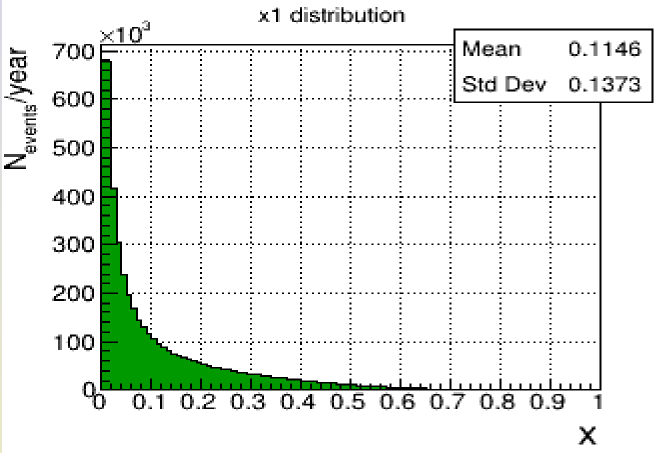




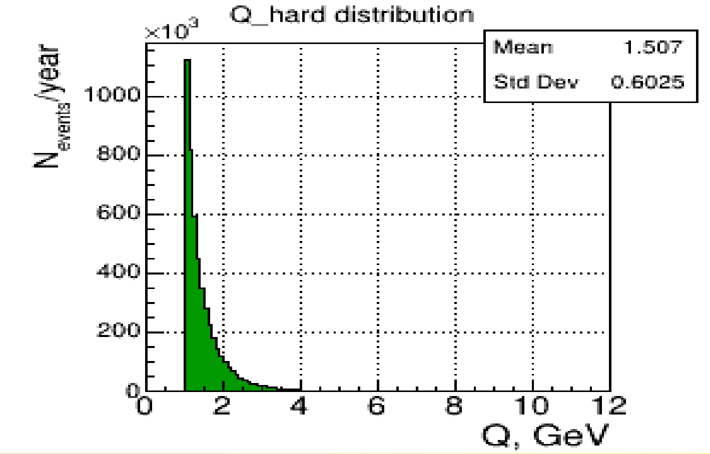


General Drell-Yan event variables for pp collision at E_{cms} =27 GeV

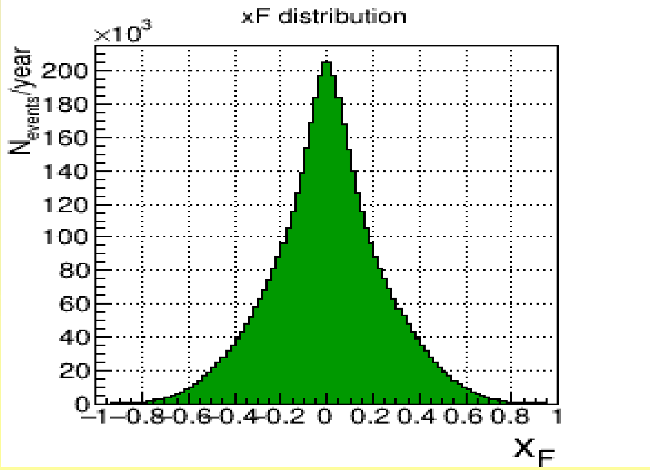
Доля импульса x, уносимая партонами



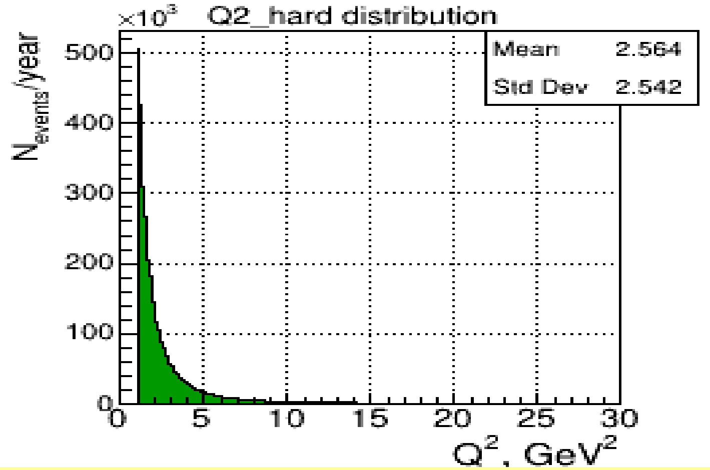
Q жесткого подпроцесса



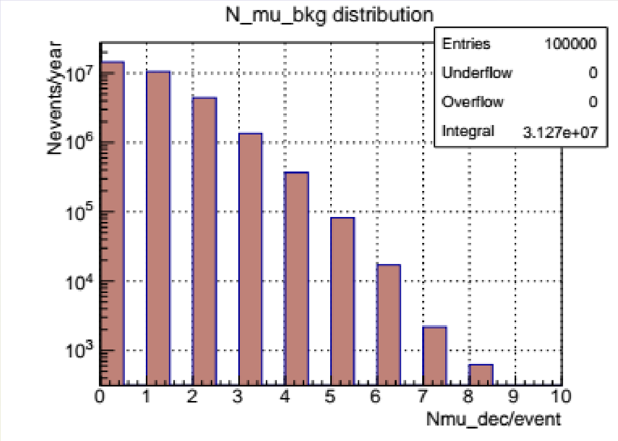
$X_F = x_1 - x_2$



Q^2 жесткого подпроцесса

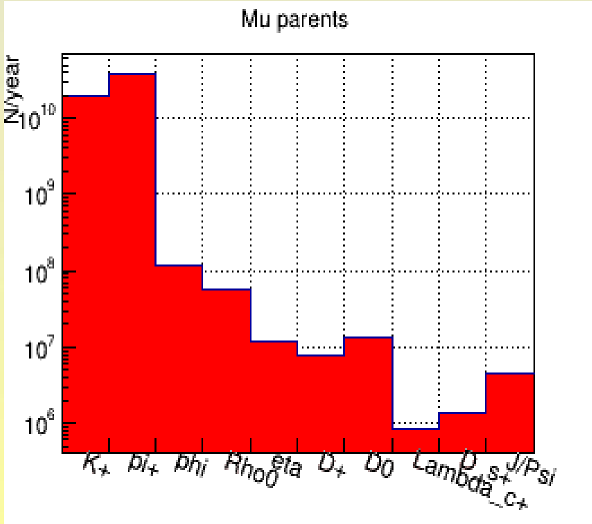


Background muons in signal events



53.5 % of signal events contais >2 muons
- up to 8μ/event

We allow particles decay (and produce muons) in the volume before Muon (Range) System :
cylindr radius **R = 2 400 mm**,
size from the centre along Z axis **L = 4 000 mm**
and search for muons in the angle region **9º< Θ < 171º**



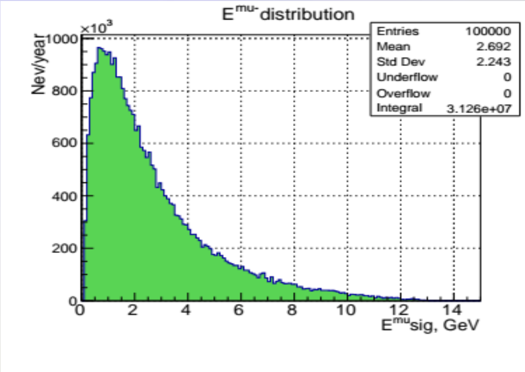
The most probable parents of bkg muons - are charged π and K

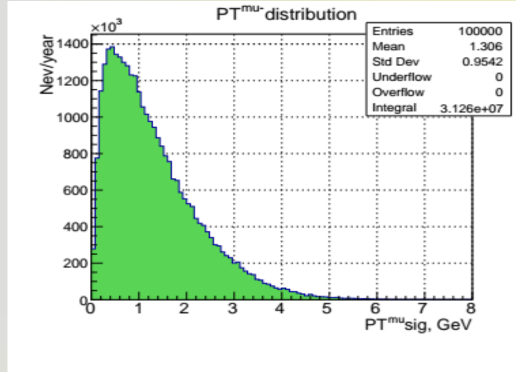
The most probable grandparents of bkg muons - are «string» (Lund model),

$\boldsymbol{\rho^{0}, \rho^{+}, K^{0}_{S}, K^{*0}, K^{+}, \eta'}$

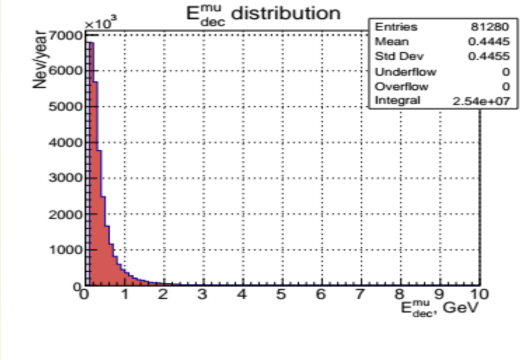
Decay muons in signal events

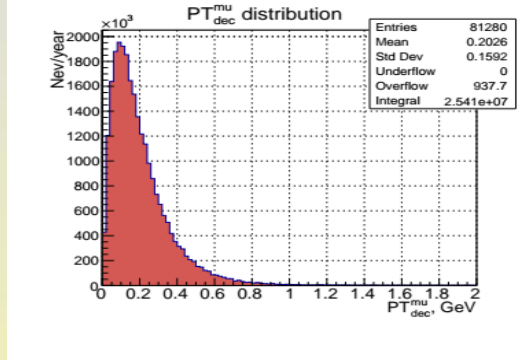
S I G



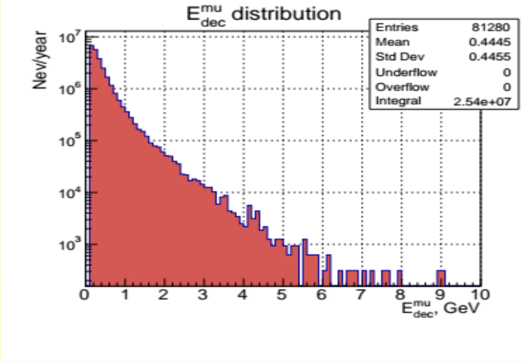


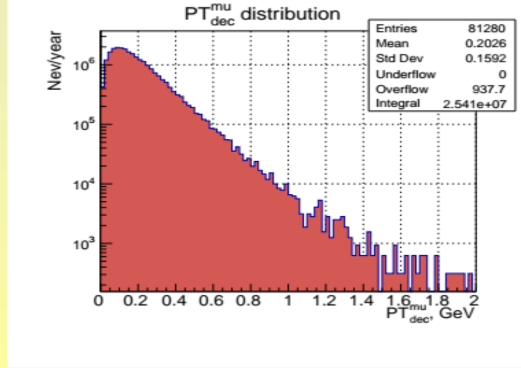
D E C





D E C (log)





Cuts : **exactly 2 muons**	**E > 0.8 GeV PT > 0.4 GeV**	**E > 1.0 GeV PT > 1.0 GeV**
Reminder of signal events	54.1%	23.5%
Fraction of initial signal events with additional muons	2.1%	0.08%
Fraction of remaining signal events with additional muons	3.9 %	0.3%

Another situation when we have exactly 2 μ —
first signal, the second — survived fake one.

We have 2 situations -

1. Muons are of the same sign — easy to cut off
2. Muons are of different signes

After cutting off the events with additional (>2) muons we have

Cuts: **exactly 2 muons with opposite signes**	E > 0.8 GeV PT > 0.4 GeV	E > 1.0 GeV PT > 1.0 GeV
Reminder of signal events	51.9%	23.4%
Fraction of initial signal events with fake muons of the same sign	0.9%	0.09%
Fraction of remaining signal events with muons of the same sign	1.7 %	0.4%
Reminder of signal events after cut off the events with the muons of the same sign	51.0%	23.4%
Fraction of initial signal events with fake muons of different sign	0.9%	0.1%
Fraction of remaining signal events with muons of different sign	1.8 %	0.4%

Processes with charmonium production

1) $q_i \bar{q}_i \to \gamma^* \to c\bar{c} \to J/\Psi \to l^+l^- + X$

86) $g\,g \to J/\Psi + g \to l^+l^- + X$ — R.Baier and R.Rücke, Z.Phys. C19 (1983) 251

106) $g\,g \to J/\Psi + \gamma \to l^+l^- + X$ — M.Drees and C.S.Kim, Z.Phys. C53 (1991) 673

421) $g\,g \to c\bar{c}\,[{}^3S_1{}^{(1)}]\,g \to ll + X$

422) $g\,g \to c\bar{c}\,[{}^3S_1{}^{(8)}]\,g \to ll + X$

423) $g\,g \to c\bar{c}\,[{}^3S_0{}^{(8)}]\,g \to ll + X$

424) $g\,g \to c\bar{c}\,[{}^3P_J{}^{(8)}]\,g \to ll + X$

425) $g\,q \to c\bar{c}\,[{}^3S_1{}^{(8)}]\,q \to ll + X$

426) $g\,q \to c\bar{c}\,[{}^3P_J{}^{(8)}]\,q \to ll + X$

427) $g\,g \to c\bar{c}\,[{}^3S_1{}^{(1)}]\,q \to ll + X$

428) $q\,\bar{q} \to c\bar{c}\,[{}^3S_1{}^{(8)}]\,g \to ll + X$

429) $q\,\bar{q} \to c\bar{c}\,[{}^1S_0{}^{(8)}]\,g \to ll + X$

430) $q\,\bar{q} \to c\bar{c}\,[{}^3P_J{}^{(8)}]\,g \to ll + X$

431) $g\,g \to c\bar{c}\,[{}^3P_0\,({}^1)]\,g \to ll + X$

432) $g\,g \to c\bar{c}\,[{}^3P_1\,({}^1)]\,g \to ll + X$

433) $g\,g \to c\bar{c}\,[{}^3P_2\,({}^1)]\,g \to ll + X$

434) $g\,q \to c\bar{c}\,[{}^3P_0\,({}^1)]\,q \to ll + X$

435) $g\,q \to c\bar{c}\,[{}^3P_1\,({}^1)]\,q \to ll + X$

436) $g\,q \to c\bar{c}\,[{}^3P_2\,({}^1)]\,q \to ll + X$

437) $q\,\bar{q} \to c\bar{c}\,[{}^3P_0\,({}^1)]\,g \to ll + X$

438) $q\,\bar{q} \to c\bar{c}\,[{}^3P_1\,({}^1)]\,g \to ll + X$

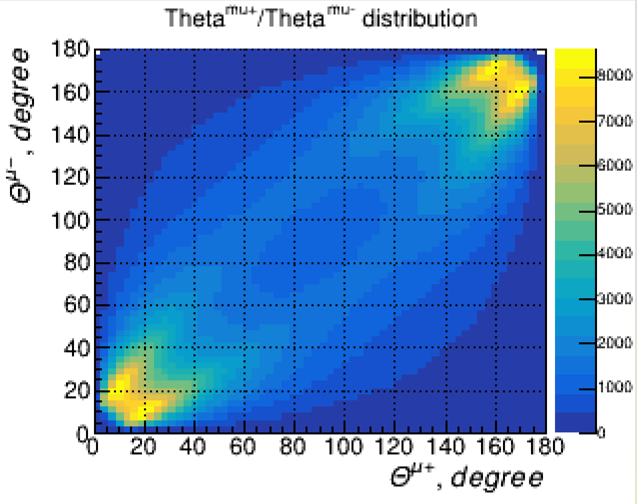
439) $q\,\bar{q} \to c\bar{c}\,[{}^3P_2\,({}^1)]\,g \to ll + X$

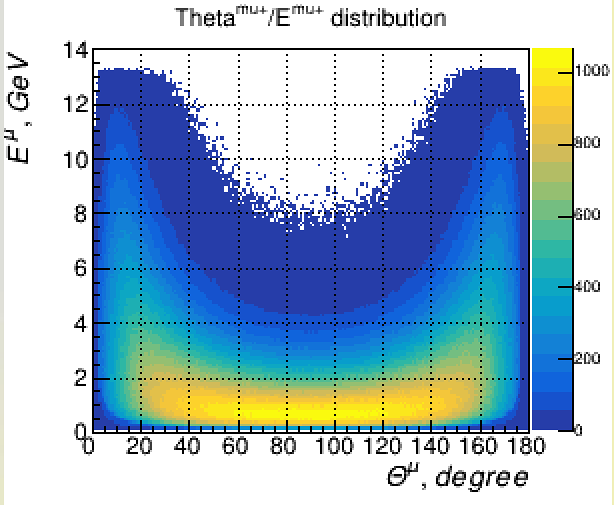
G.T.Badwin, E.Braten and G.P.Lepage, Phys.Rev. D51 (1995) 1125 [Erratum: ibid D55 (1997) 5883];

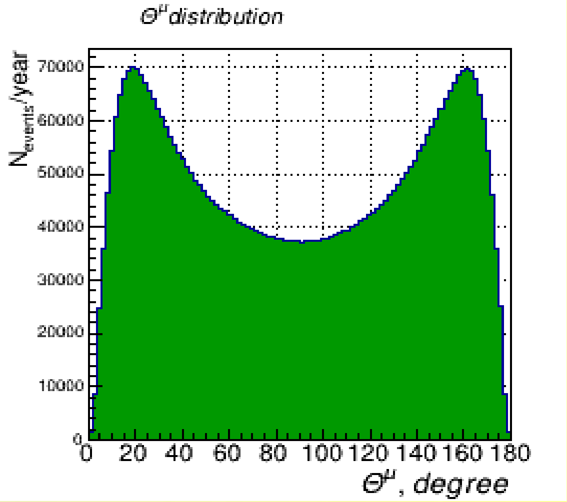
M.Beneke, MKrämer and M.Vänttinen, Phys.Rev.D57 (1998) 4258;

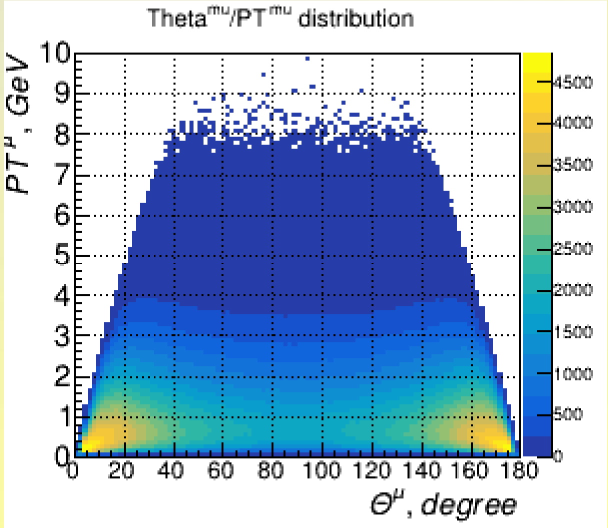
B.A.Kniehl and J.Lee, Phys.Rev. D62 (2000) 114027

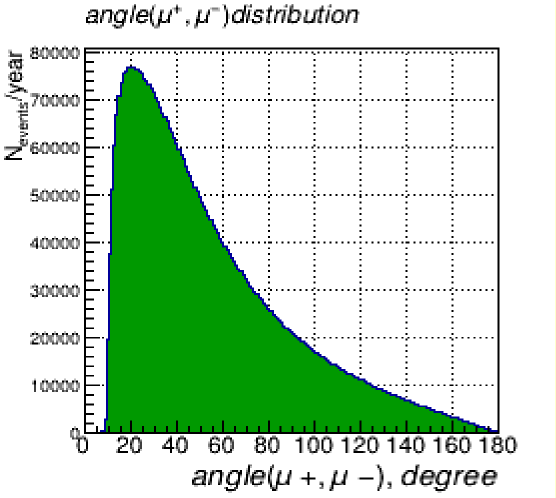
Some signal μ correlation distributions



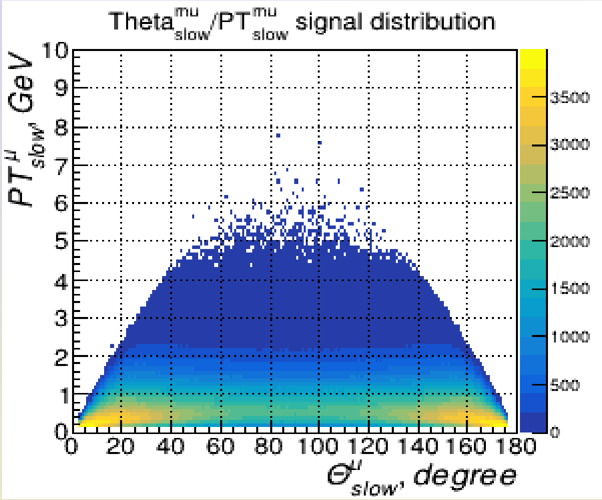


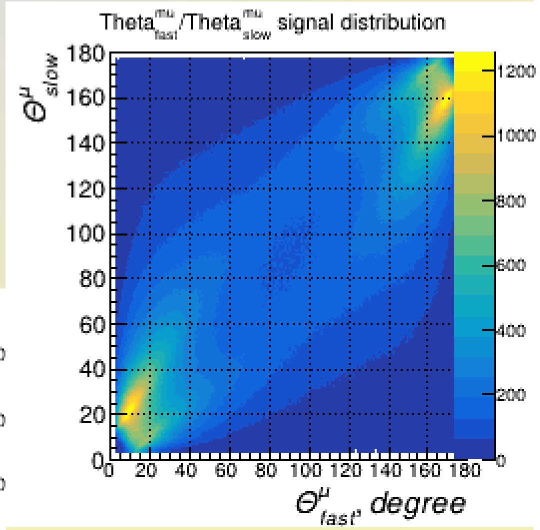


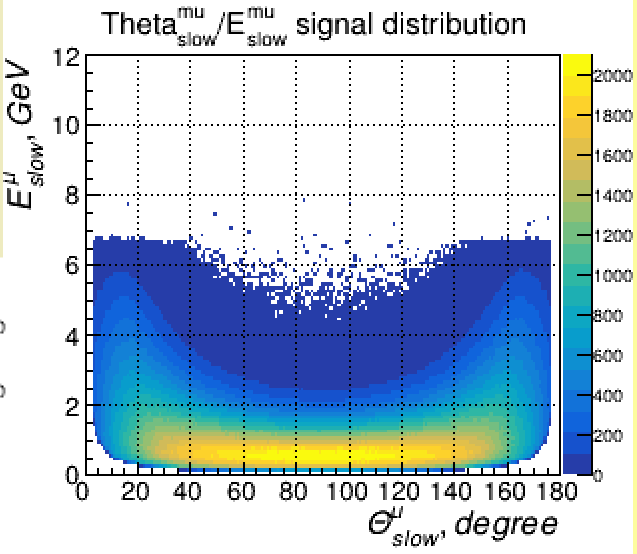


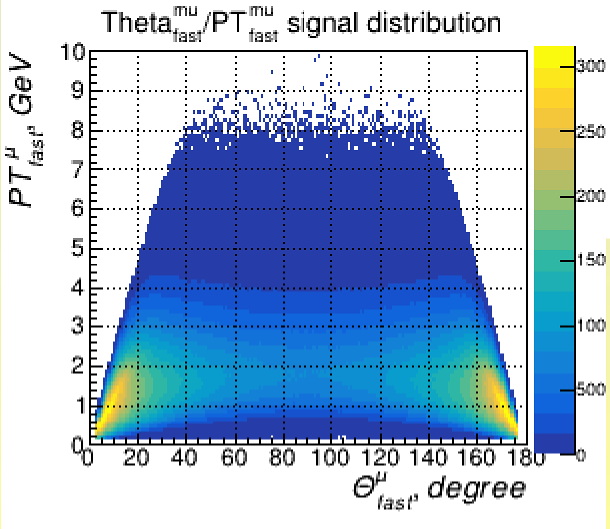


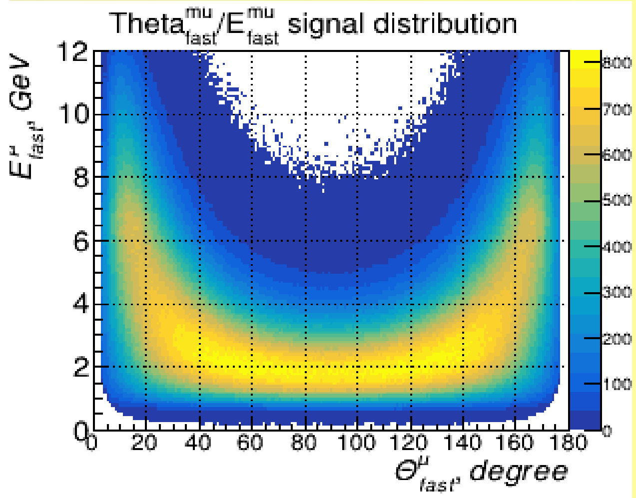
Angle and E, PT for fast and slow signal μ correlation distributions



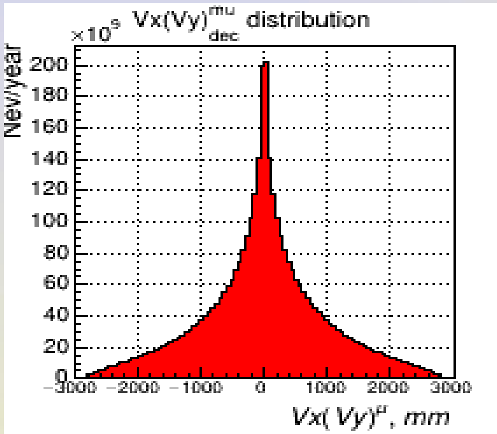


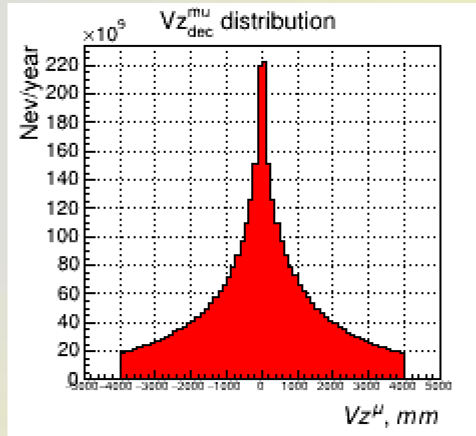


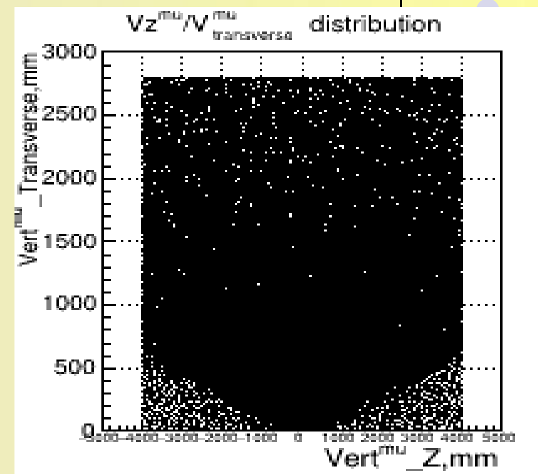




Vertex & angle distributions







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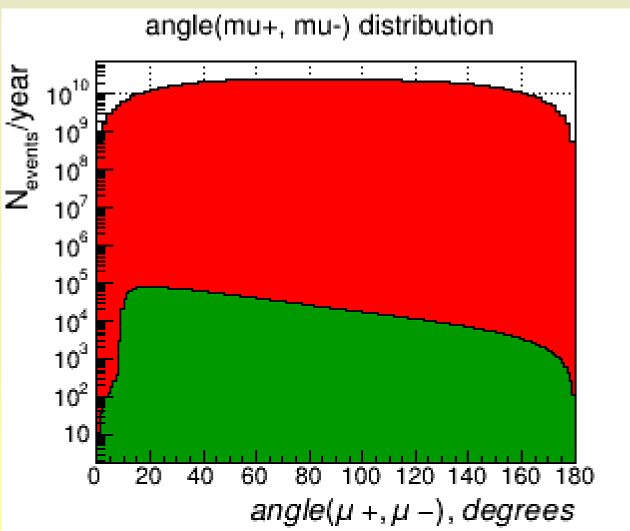

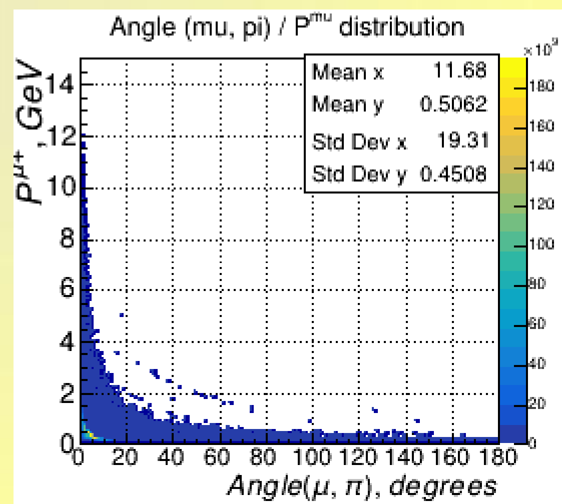

π/μ rejection

For 5λ of path length in iron.

Particle momentum	**π/μ rejection**
0.5 — 1 GeV	~ 80 % (experiment with MS prototype)
1 — 1.5 GeV	~ 90 % (assumption)
> 1.5 GeV	~ 99 % (assumption)

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The path length of a charged particle track inside the sandwich structure serves as one of the most powerful variables for μ/π separation, which is challenging due to the similar rest mass of muon and pion

for **3λ** path length (+4.9 % muon misidentification)
for **4λ** path length (+1.8 % muon misidentification)
for **5λ** path length (+0.67 % muon misidentification)

$\boldsymbol{\lambda}_{\mathbf{FE}}$ ~= 17cm

Cuts separate and summarized efficiency for Open Charm background events (10^7)

Efficiency Eff (K,N) = Nev(cutN) / Nev(cutK)

N of cuts	S/B ratio	*Efficiency for BKG*	Rest of BKG	*Efficiency for SIG*	Rest of SIG
1 ***Exactly 2μ*** with **PT$^{\mu}$ > 0.6 GeV, P(E)$^{\mu}$ > 1.0 GeV**	**0.10**	Eff (1,init) = **47.14**	2.1 %	2.45	40.8 %
2^{+1} ***2μ** are of the* ***opposite sign***	**0.12**	Eff (2,1) = **1.21**	1.7 %	1.01	40.5 %
3^{+2+1} ***M_{inv} (μ+,μ-) > 1.0 GeV***	**0.14**	Eff (3,2) = **1.19**	1.4 %	1.01	40.0 %
4^{+3+2+1} ***PT^{μ}_{Emax} > 1.5 GeV***	**0.82**	Eff (4,3) = **8.77**	1.7×10^{-1} %	1.53	26.2 %
5^{+3+2+1} ***E^{all}_{sum} > 26.8 GeV***	**263.3**	Eff (5,3) = **5401**	2.7×10^{-4} %	2.93	13.6 %
6^{+3+2+1} ***PT^{all}_{vecsum} < 0.2 GeV***	**1.18**	Eff (6,3) = **14.31**	1.0×10^{-1} %	1.73	23.1 %
7^{+3+2+1} ***P^{all}_{vecsum} < 0.2 GeV***	**7.04**	Eff (7,3) = **131.6**	1.1×10^{-2} %	2.67	15.0 %
8^{+3+2+1} ***Isolation criterium***	**> 20433**	Eff (8,3) **> 145845**	< 1.0×10^{-5} %	1.02	**39.3 %**
9^{+3+2+1} ***R_{vertex} < 1 mm***	**764.8**	Eff (9,3) = **5401**	2.7×10^{-4} %	1.01	39.7 %
10^{+3+2+1} ***R_{vertex} < 30 mm***	**18.6**	Eff (10,3) = **131.6**	1.1×10^{-2} %	1.01	39.7 %
$5^{+4+3+2+1}$ ***E^{all}_{sum}*** **> 26.8 GeV**	**1306**	Eff (5,4) = **4157**	4.0×10^{-5} %	2.61	**10.0 %**
$8^{+4+3+2+1}$ **Isolation criterium**	**> 13238**	Eff (8,4) > **16627**	< 1.0×10^{-5} %	1.03	**25.4 %**
$8^{+5+4+3+2+1}$ **Isolation criterium**	**> 5178**	Eff (8,5) > **4**	< 1.0×10^{-5} %	1.01	**9.95 %**