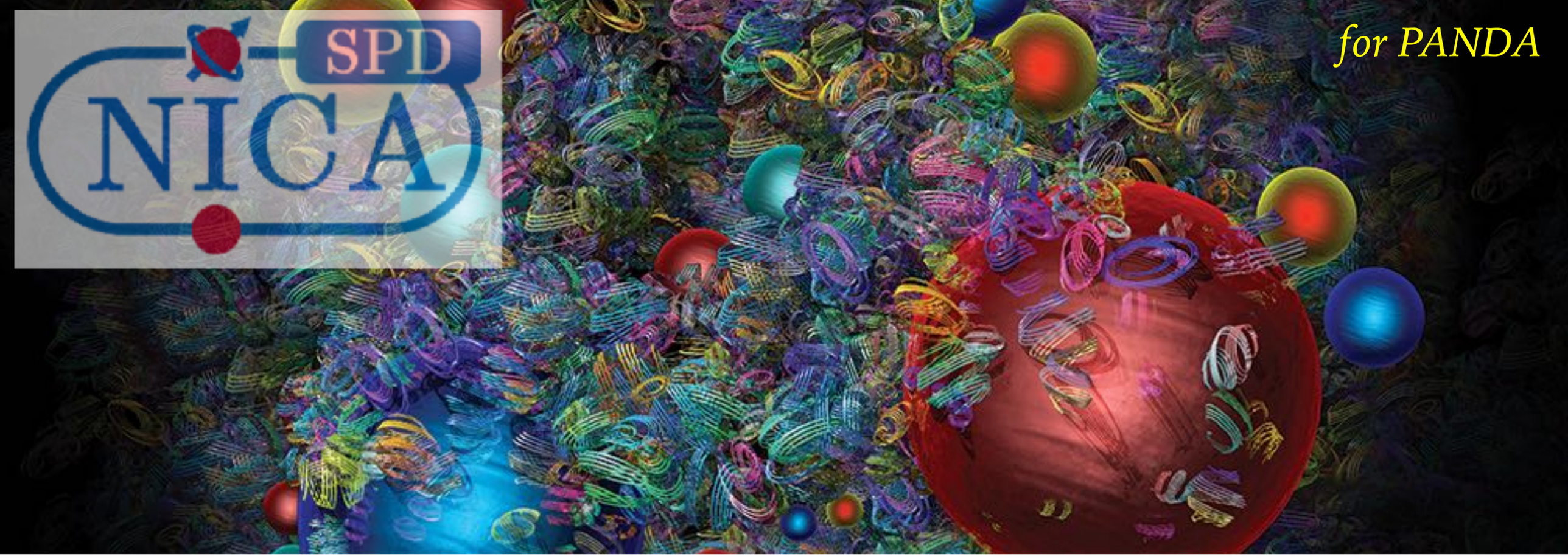


SPIN PHYSICS DETECTOR PROJECT AT JINR (DUBNA)

Alexey Guskov, JINR

on behalf of the SPD collaboration

Alexey.Guskov@cern.ch

28.5.2021

THE JOINT INSTITUTE FOR NUCLEAR RESEARCH, DUBNA, RUSSIA

The Joint Institute for Nuclear Research is an international intergovernmental scientific research organization in the science city Dubna of the Moscow region (Russia)

SPD AT NICA

NICA - Nuclotron-based Ion Collider fAcility

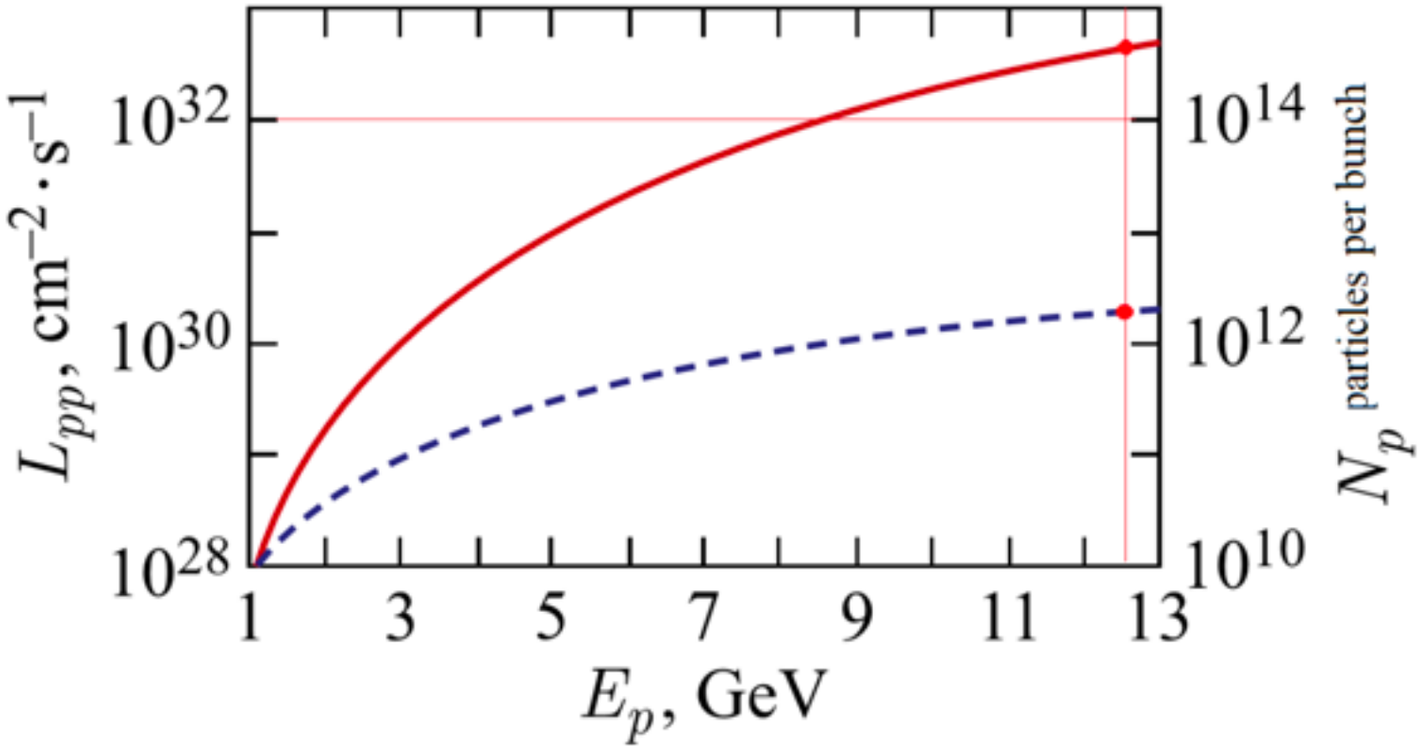
$p^{\uparrow}p^{\uparrow} : \sqrt{s} \leq 27\ GeV$

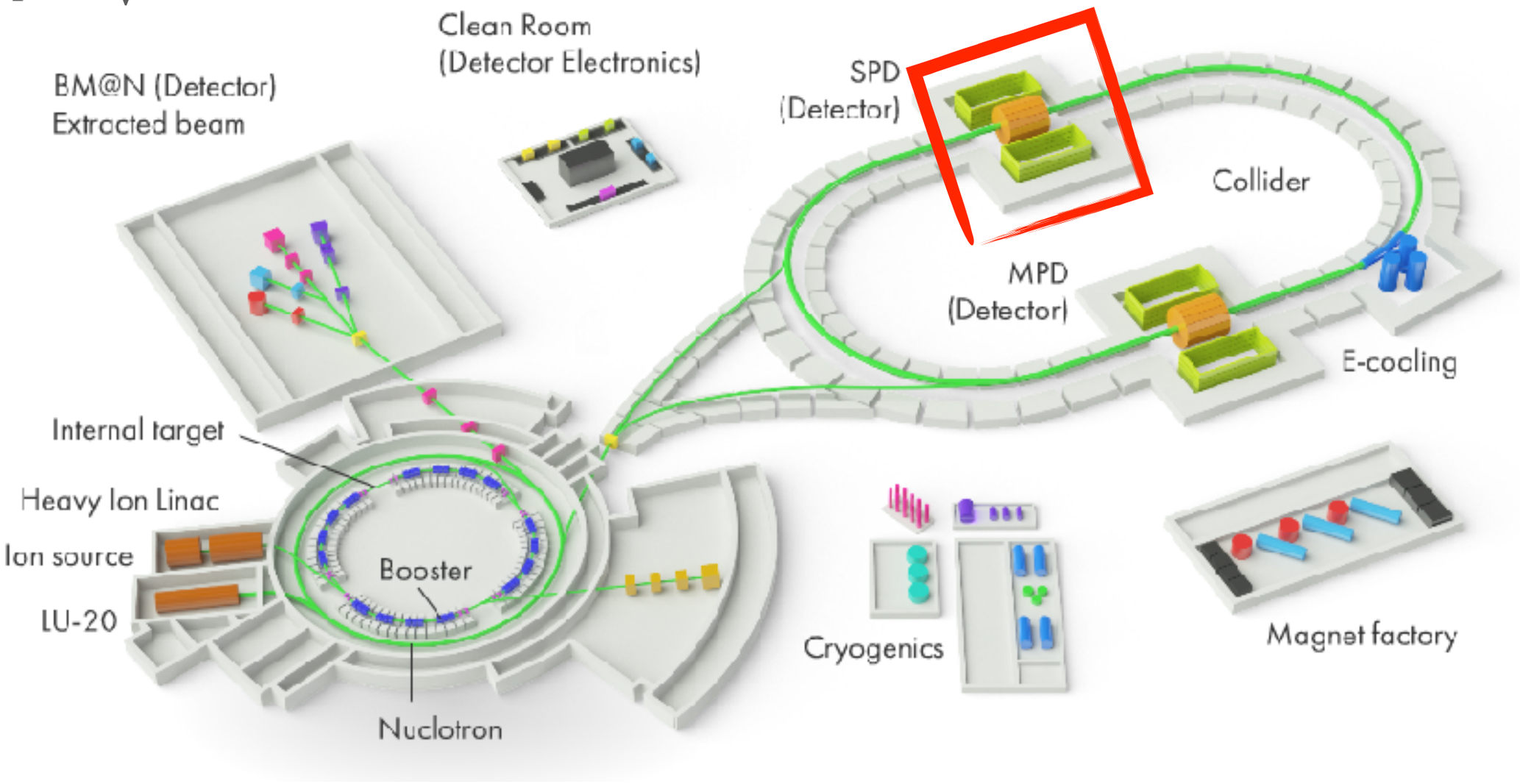
$d^{\uparrow}d^{\uparrow} : \sqrt{s} \leq 13.5\ GeV$

$d^{\uparrow}p^{\uparrow} : \sqrt{s} \leq 19\ GeV$

U, L, T

|P|>70%

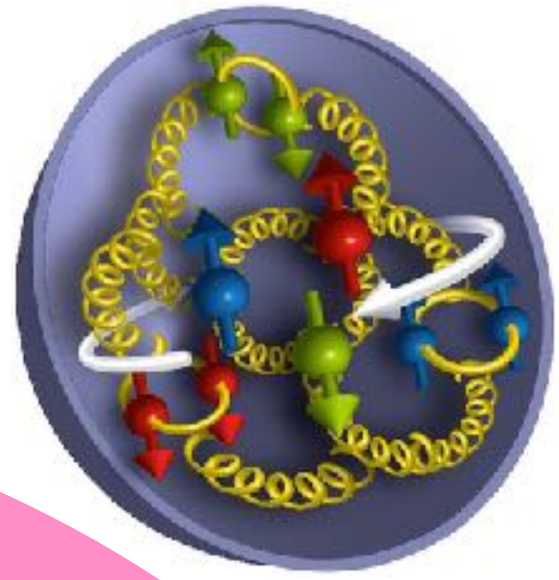




503 m


MPD
SPD

CONCEPT OF THE SPD PHYSICS PROGRAM



SPD - a universal facility for comprehensive study of gluon content in proton and deuteron at large x

Charmonia

Prompt photons

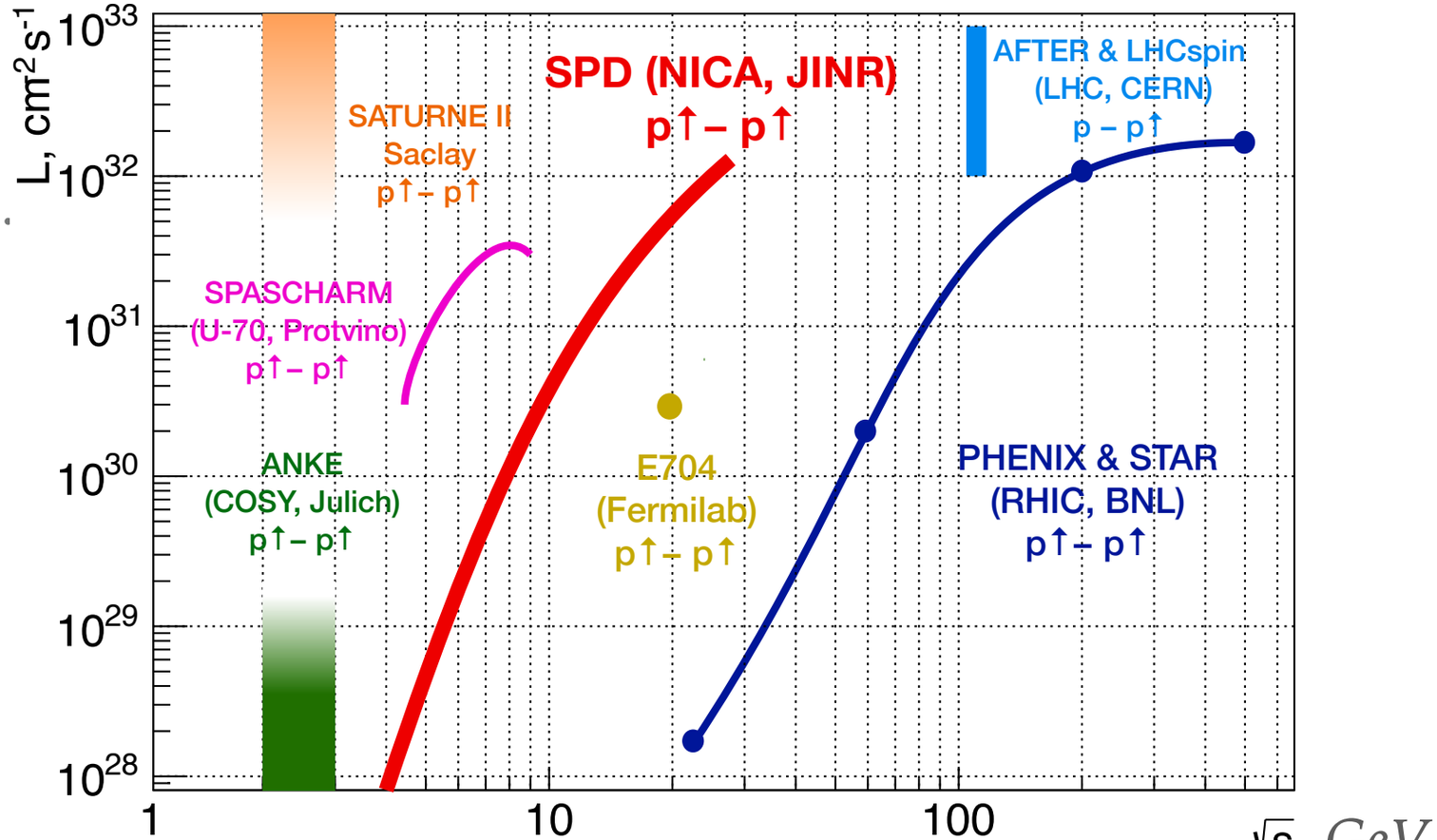
Open charm

Other spin-related phenomena

Other physics

SPD – VS OTHERS

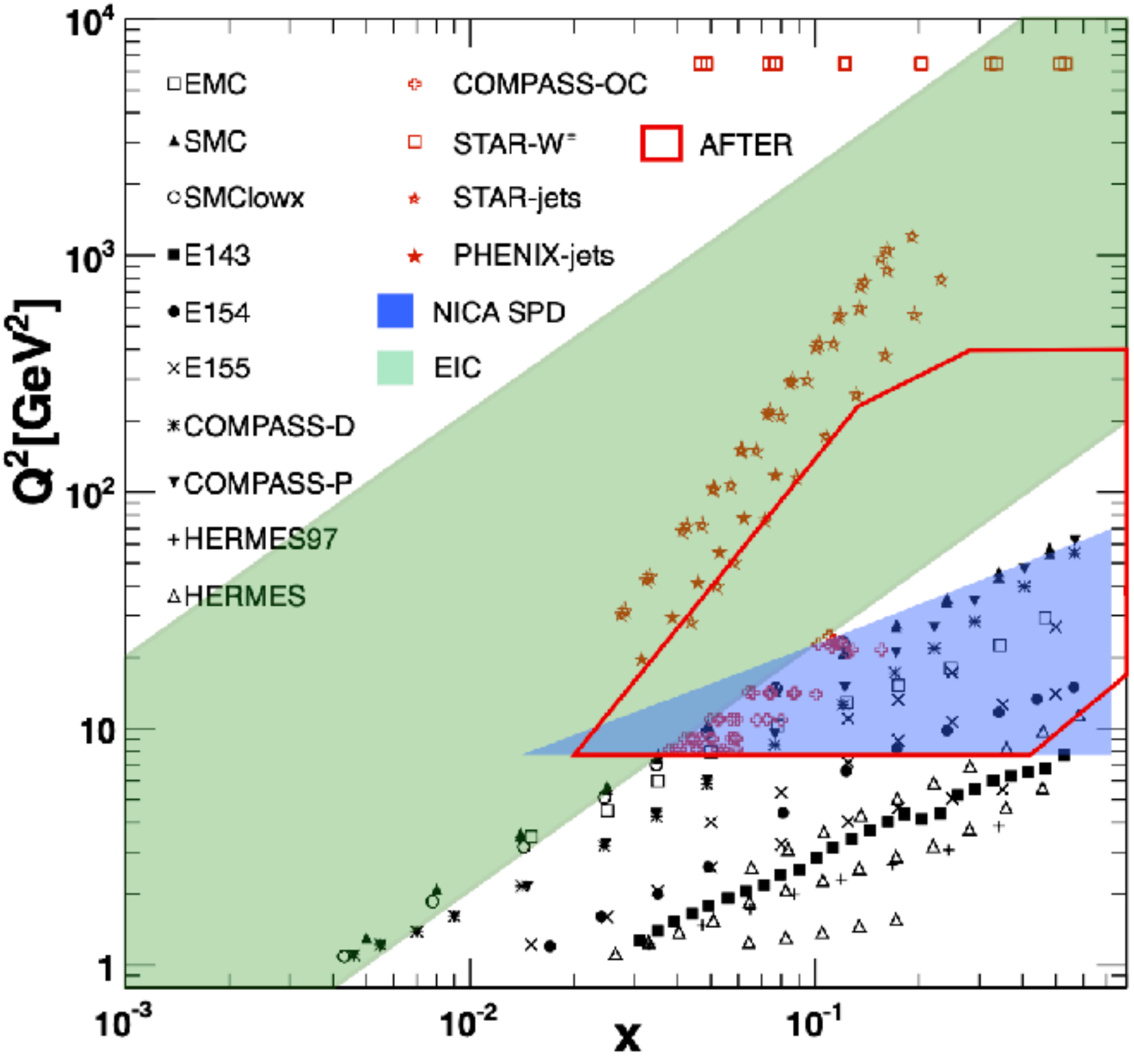
In the $p^{\uparrow}p^{\uparrow}$ mode:



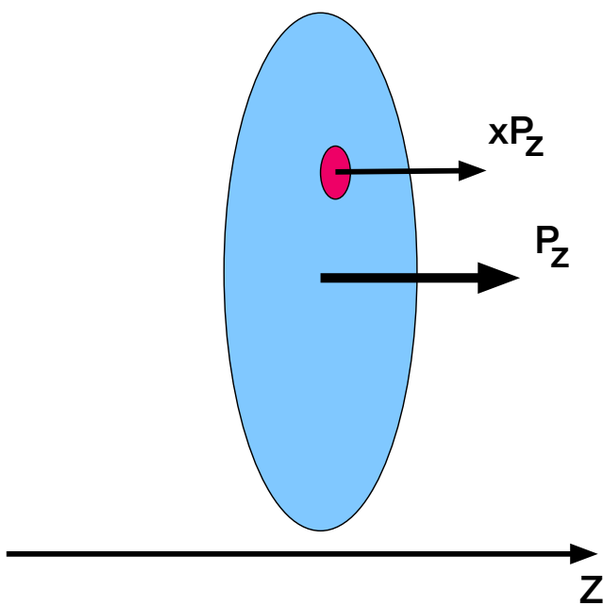
Experimental facility	SPD @NICA	RHIC	EIC	AFTER @LHC	LHCspin
Scientific center	JINR	BNL	BNL	CERN	CERN
Operation mode	collider	collider	collider	fixed target	fixed target
Colliding particles & polarization	$p^{\uparrow}$-$p^{\uparrow}$ $d^{\uparrow}$-$d^{\uparrow}$ $p^{\uparrow}$-d, p-$d^{\uparrow}$	$p^{\uparrow}$-$p^{\uparrow}$	$e^{\uparrow}$-$p^{\uparrow}$, $d^{\uparrow}$, ^{3}He$^{\uparrow}$	p-$p^{\uparrow}$, $d^{\uparrow}$	p-$p^{\uparrow}$
Center-of-mass energy $\sqrt{s_{NN}}$, GeV	≤27 (p-p) ≤13.5 (d-d) ≤19 (p-d)	63, 200, 500	20-140 (ep)	115	115
Max. luminosity, 10^{32} cm^{-2} s^{-1}	~1 (p-p) ~0.1 (d-d)	2	1000	up to ~10 (p-p)	4.7
Physics run	>2025	running	>2030	>2025	>2025

In the $d^{\uparrow}d^{\uparrow}$ mode we are unique

CINEMATIC RANGE

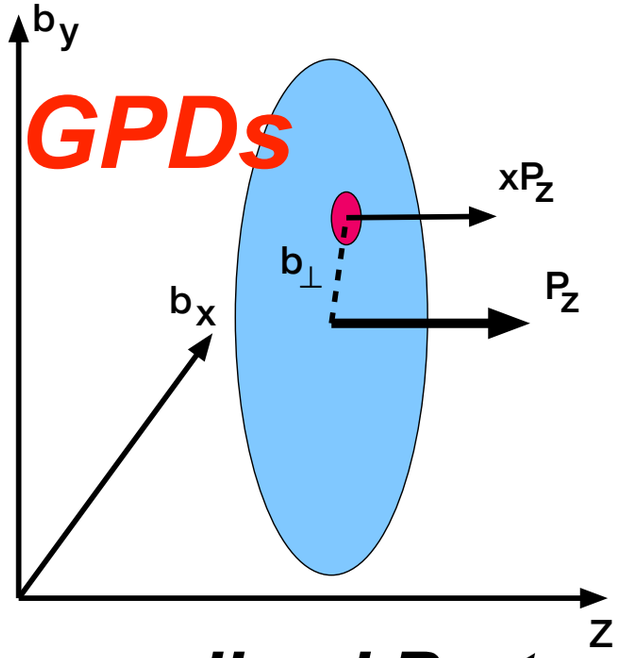


3D STRUCTURE OF THE PROTON

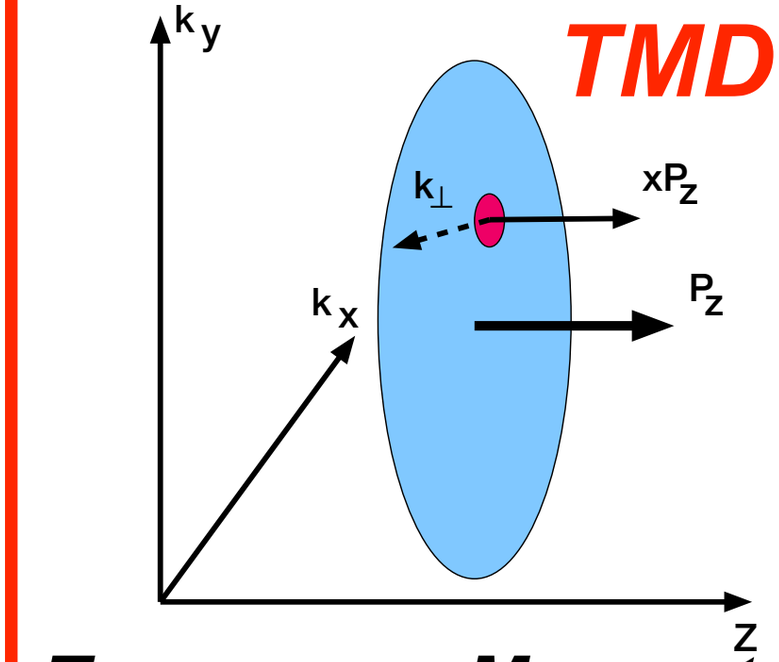


Collinear approximation

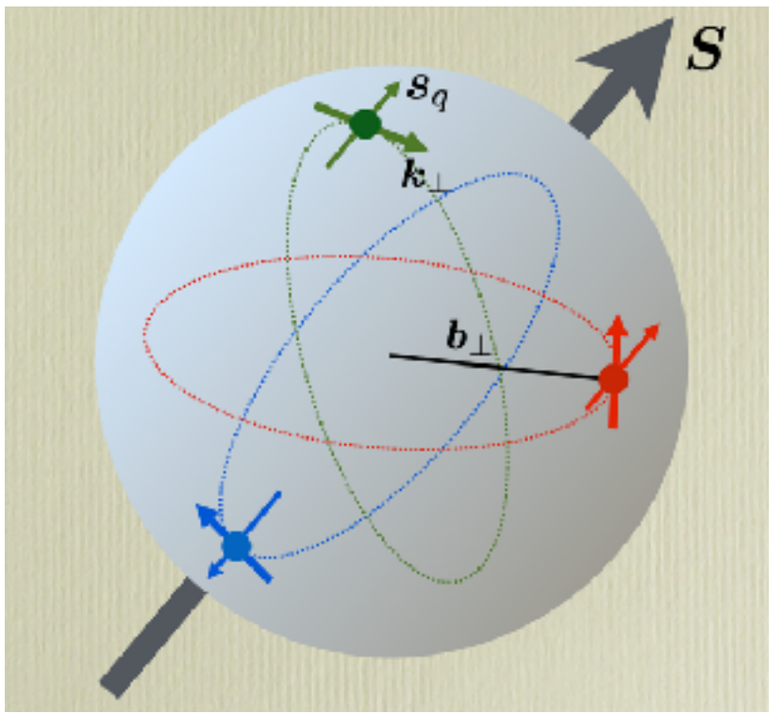
(common PDF)



Generalized Parton Distributions



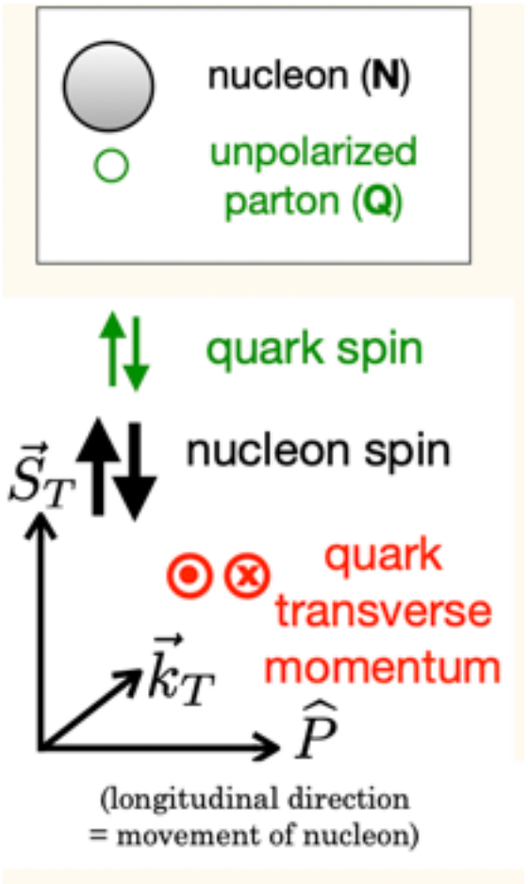
Transverse Momentum Dependent PDFs

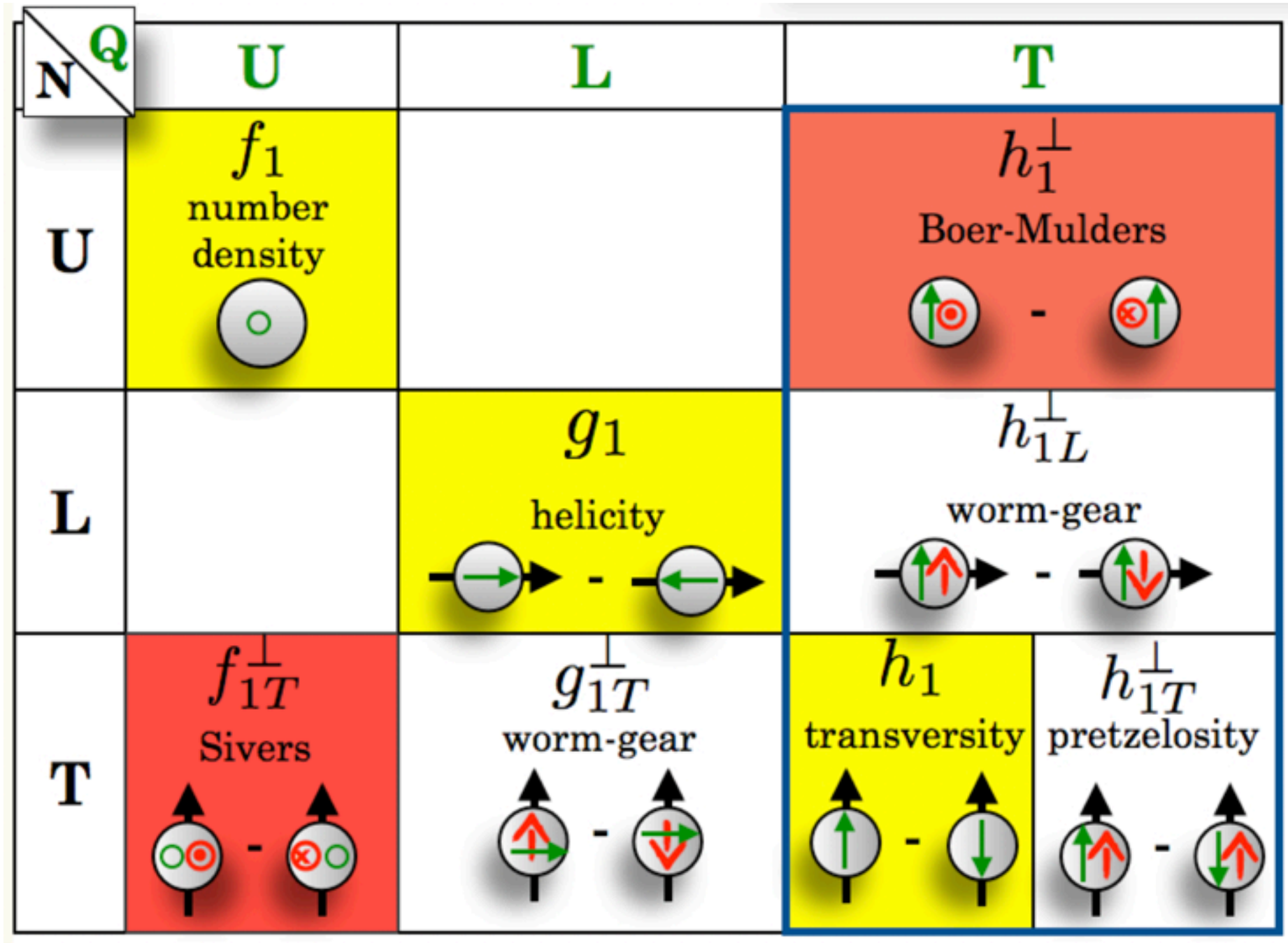


3D structure of nucleon

connection to orbital moment

TMD PDFS


nucleon (N)
unpolarized parton (Q)
quark spin
nucleon spin
$\vec{S}_T$
quark transverse momentum
$\vec{k}_T$
$\hat{P}$
(longitudinal direction = movement of nucleon)


N \ Q
U
L
T
U
f_1
number density
$h_1^\perp$
Boer-Mulders
L
g_1
helicity
$h_{1L}^\perp$
worm-gear
T
$f_{1T}^\perp$
Sivers
$g_{1T}^\perp$
worm-gear
h_1
transversity
$h_{1T}^\perp$
pretzelosity

GLUON PDFs

arXiv:2011.15005

Unpolarized gluons at high x in proton and deuteron

Gluon helicity

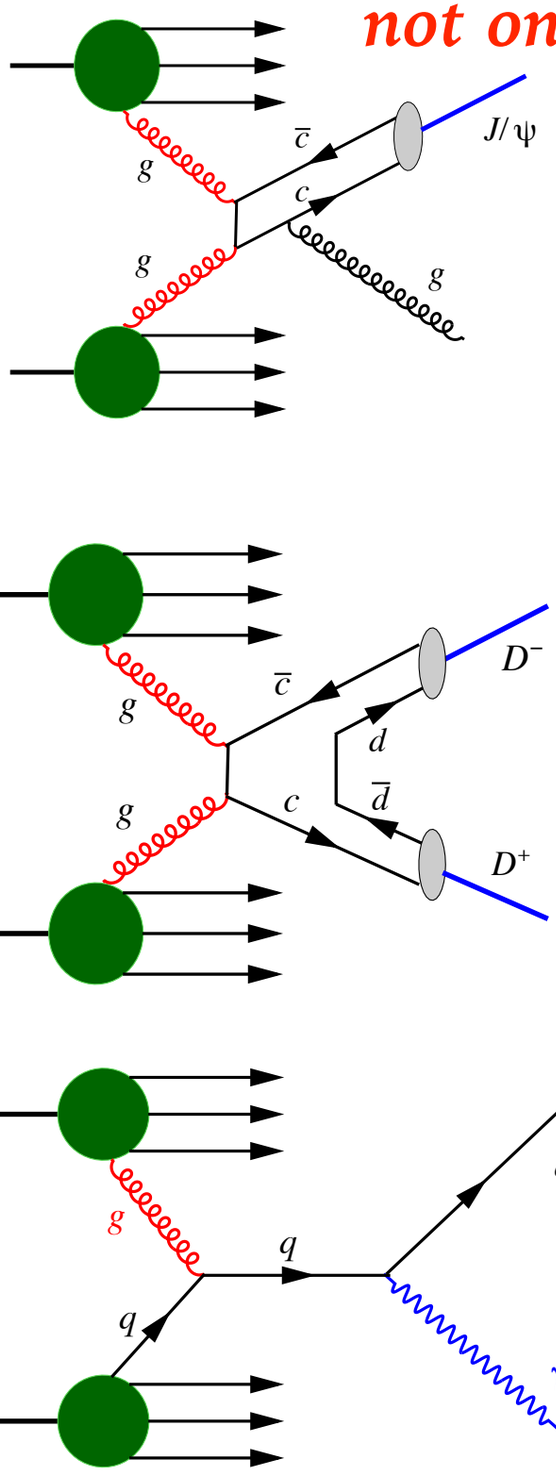
Gluon Boer-Mulders function

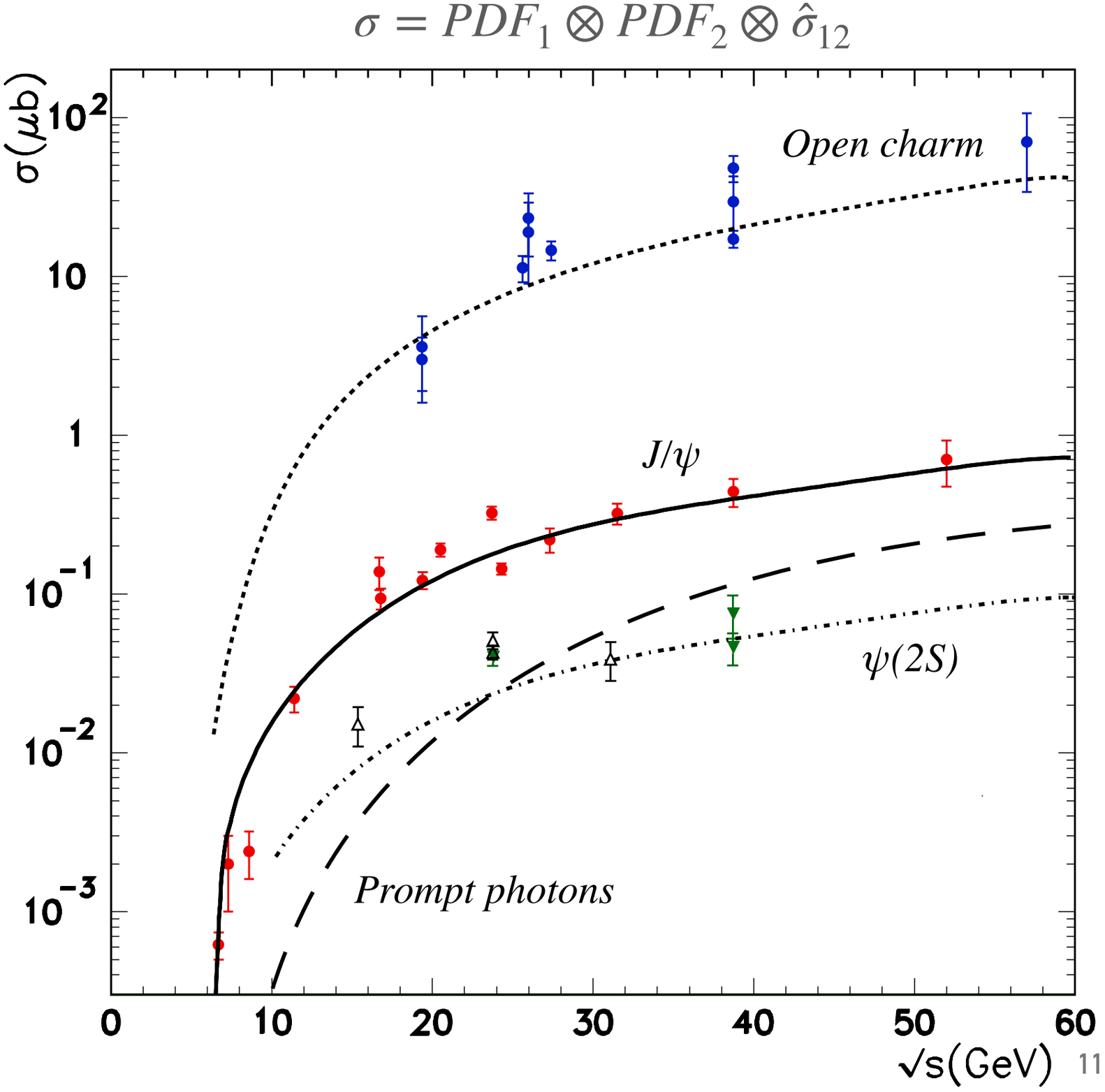
GLUONS	*unpolarized*	*circular*	*linear*
U	f_1^g		$h_1^{\perp g}$
L		g_{1L}^g	$h_{1L}^{\perp g}$
T	$f_{1T}^{\perp g}$	g_{1T}^g	$h_{1T}^g, h_{1T}^{\perp g}$

Gluon Sivers function

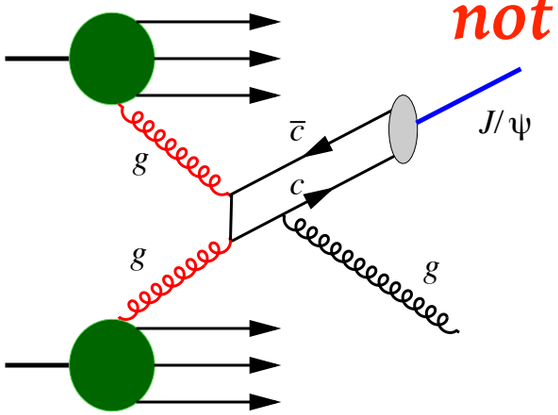
Gluon transversity in deuteron

GLUON PROBES AT SPD





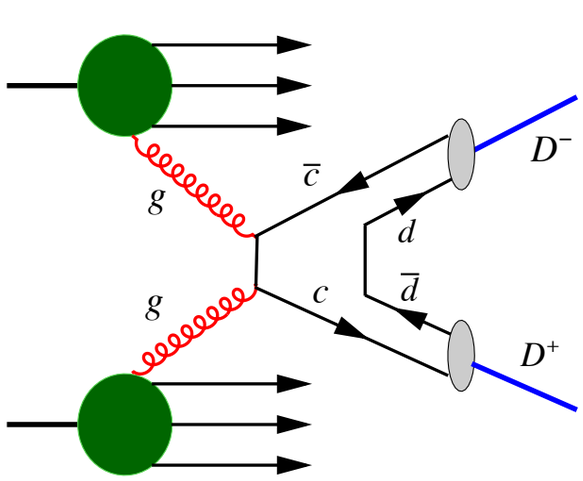
GLUON PROBES AT SPD



not only J/ψ!

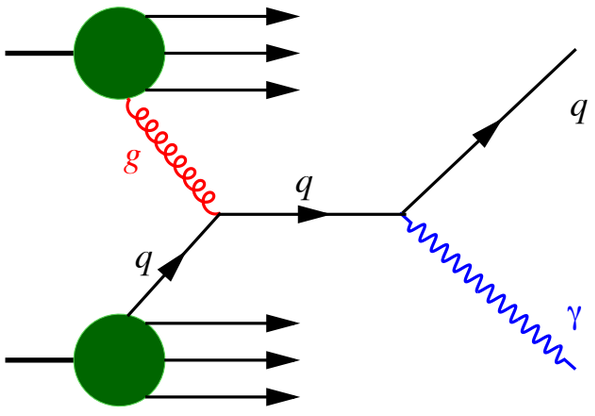
Sharp signal
Relatively large cross section

Model-dependent probability for $c\bar{c} \to [c\bar{c}]$



Largest cross section

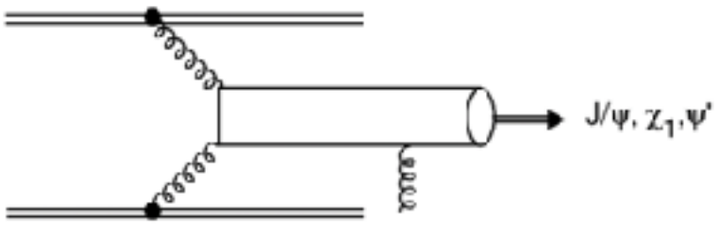
Challenging experimental requirements
Model-dependent fragmentation functions



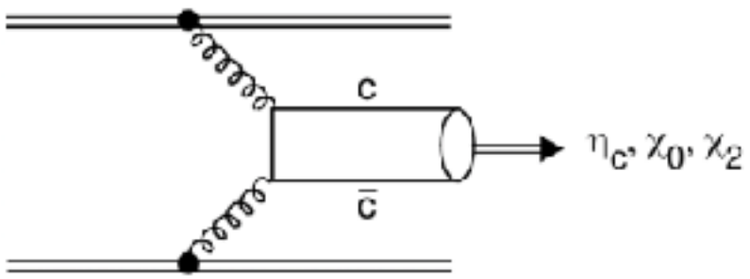
Almost no fragmentation

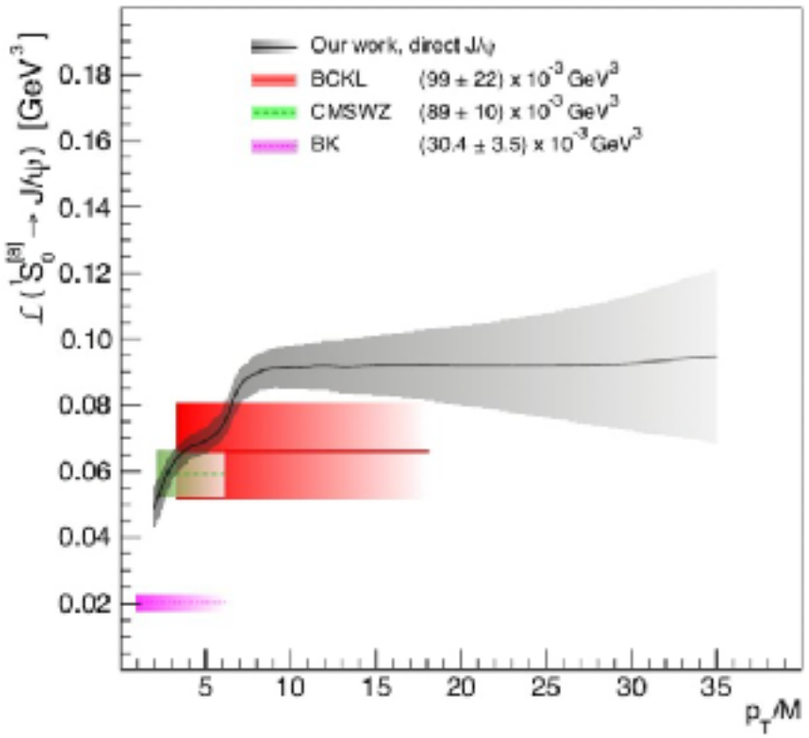
Strong background especially at low p_T

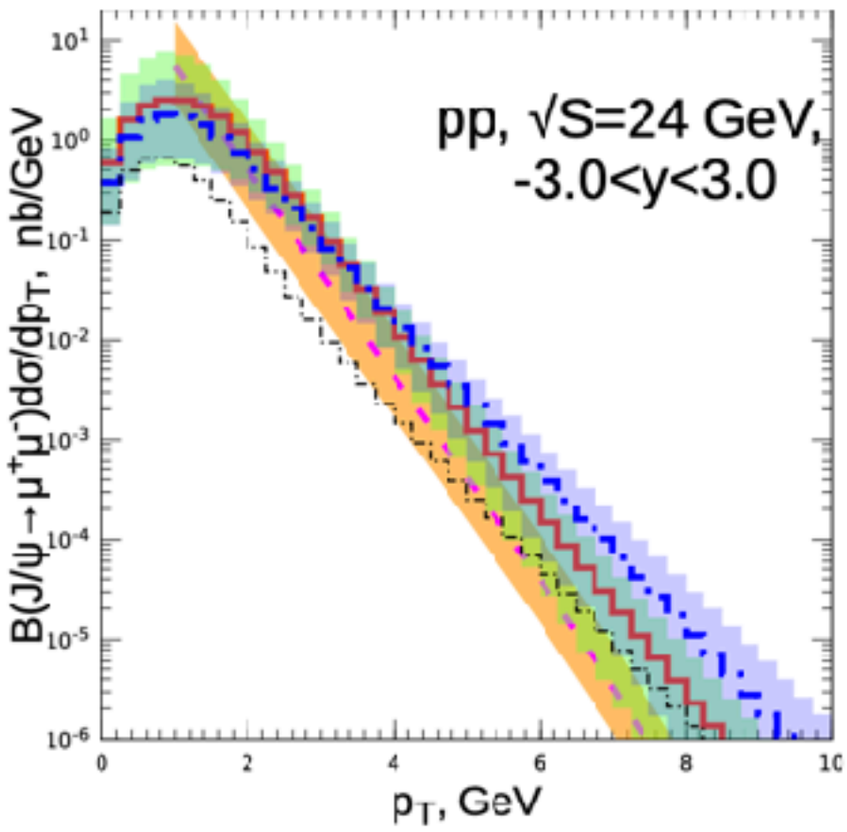
CHARMONIA PRODUCTION

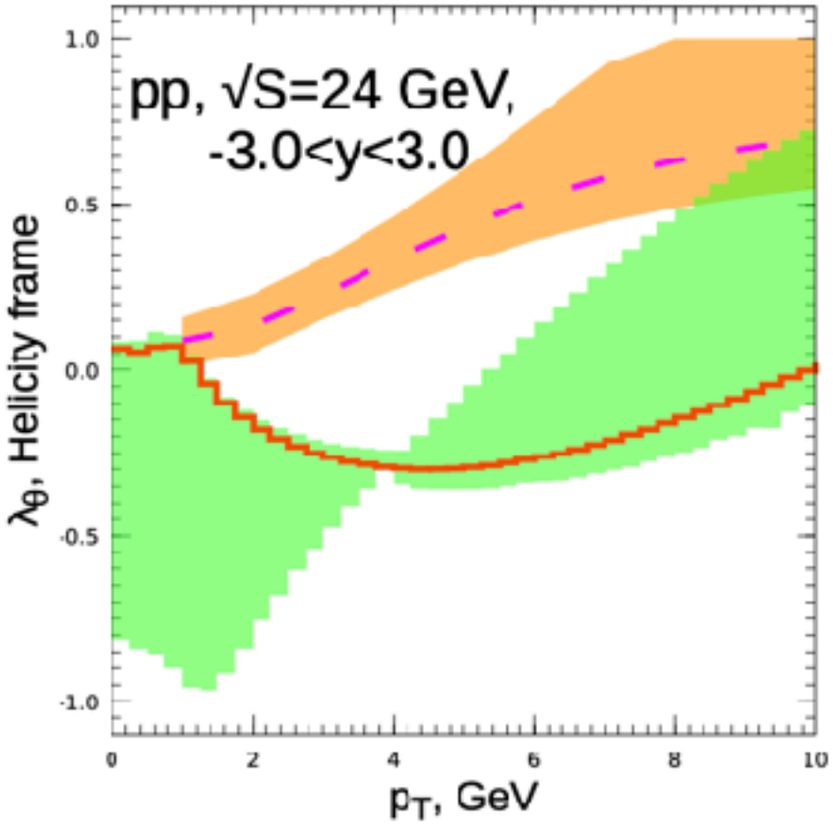


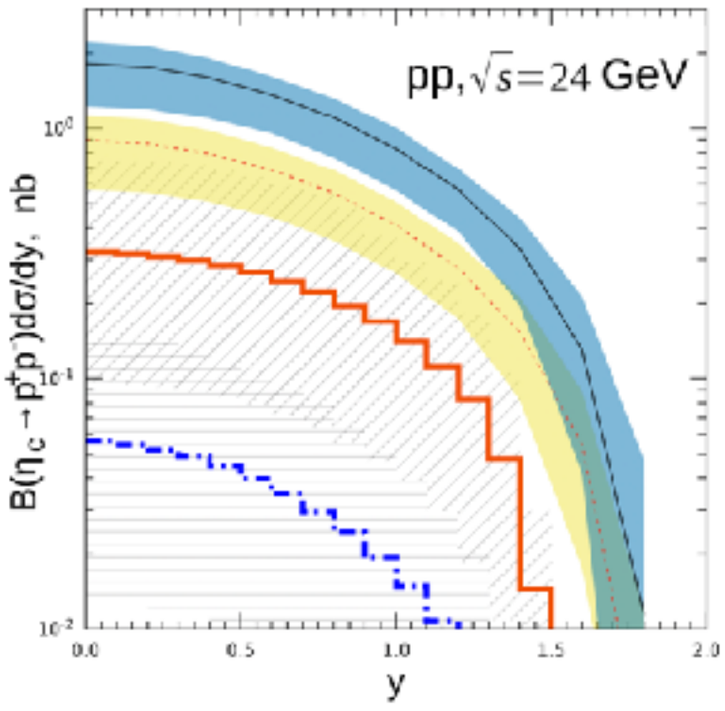
NRQCD — LDMEs



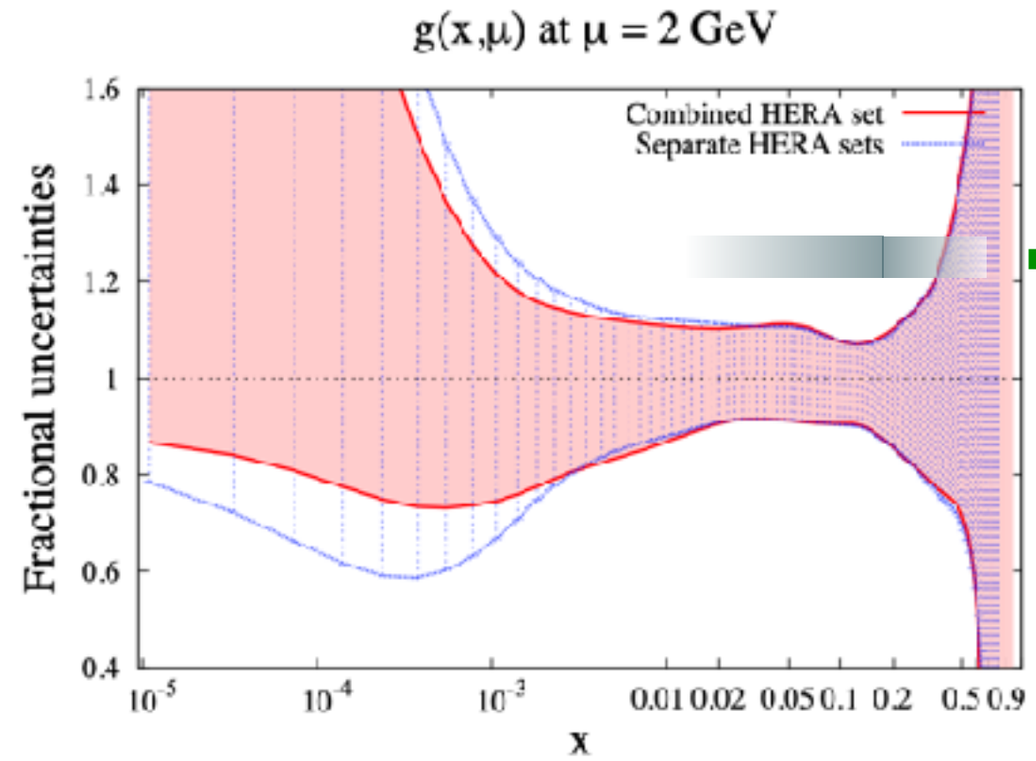




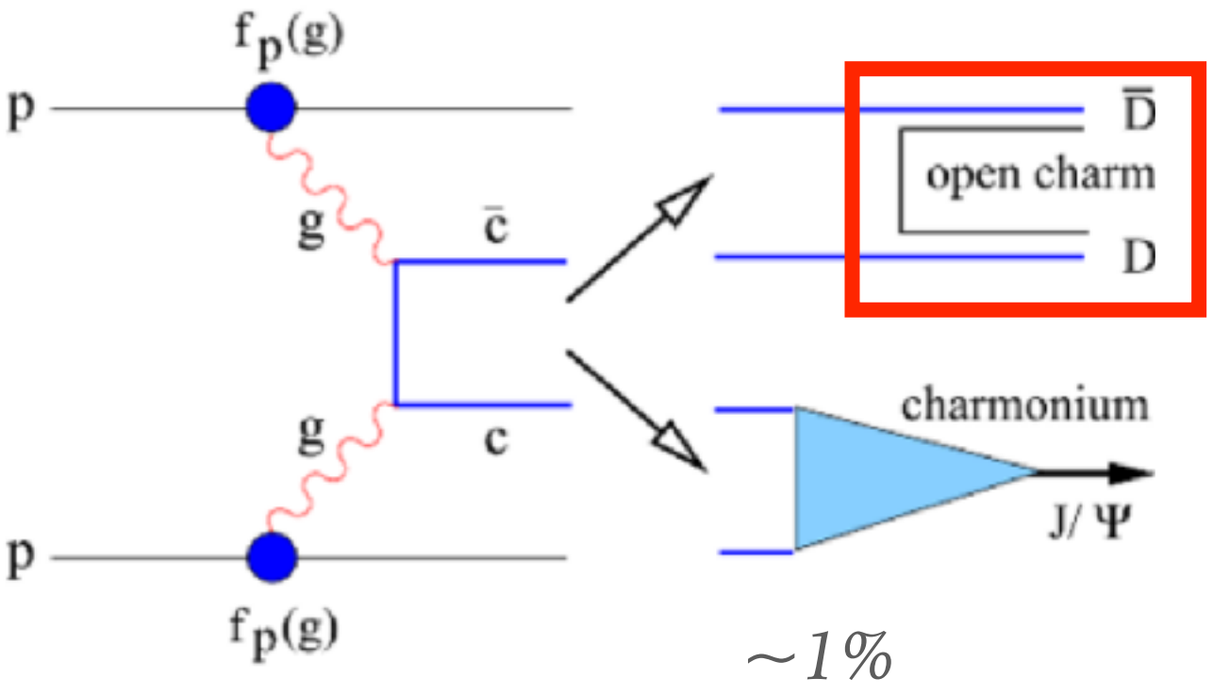




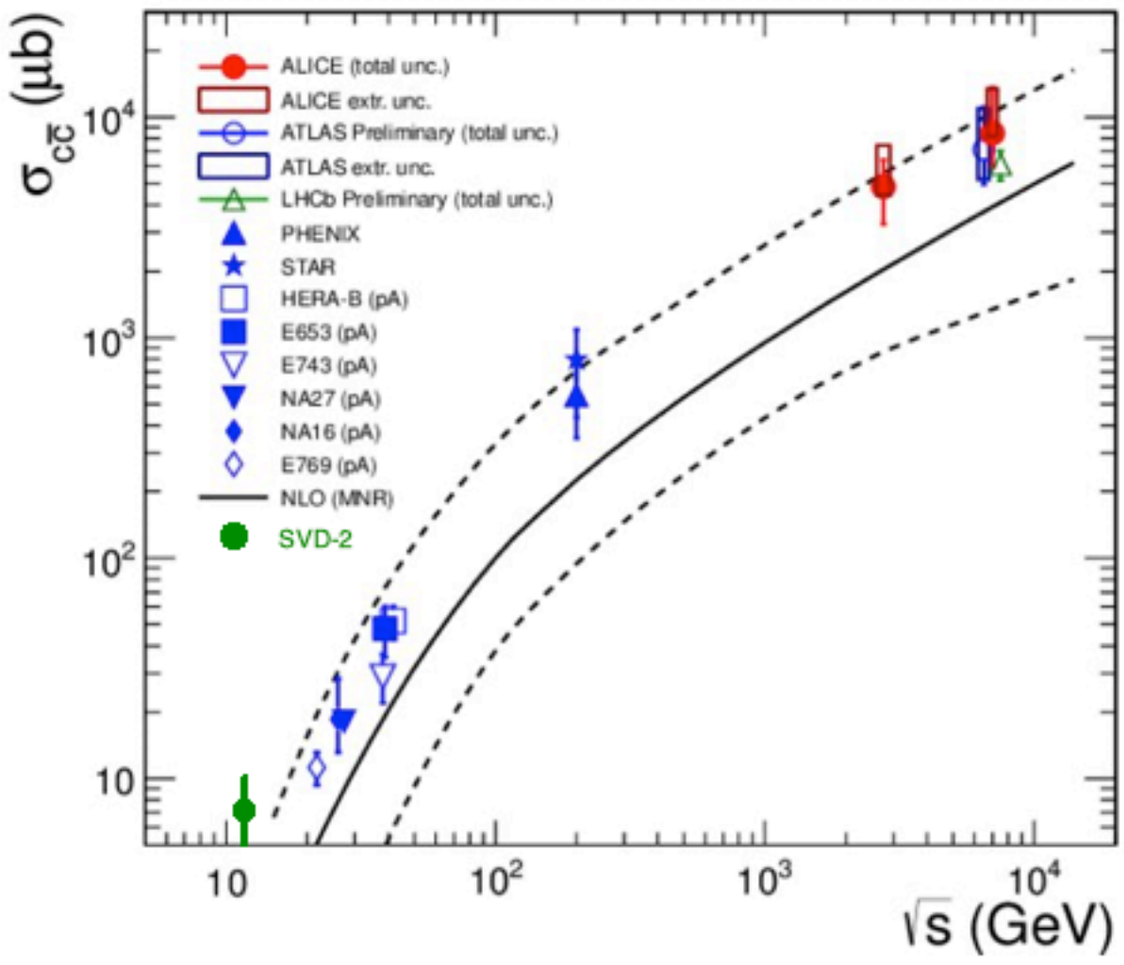
UNPOLARIZED GLUONS IN PROTON AT HIGH x



Good opportunity for SPD

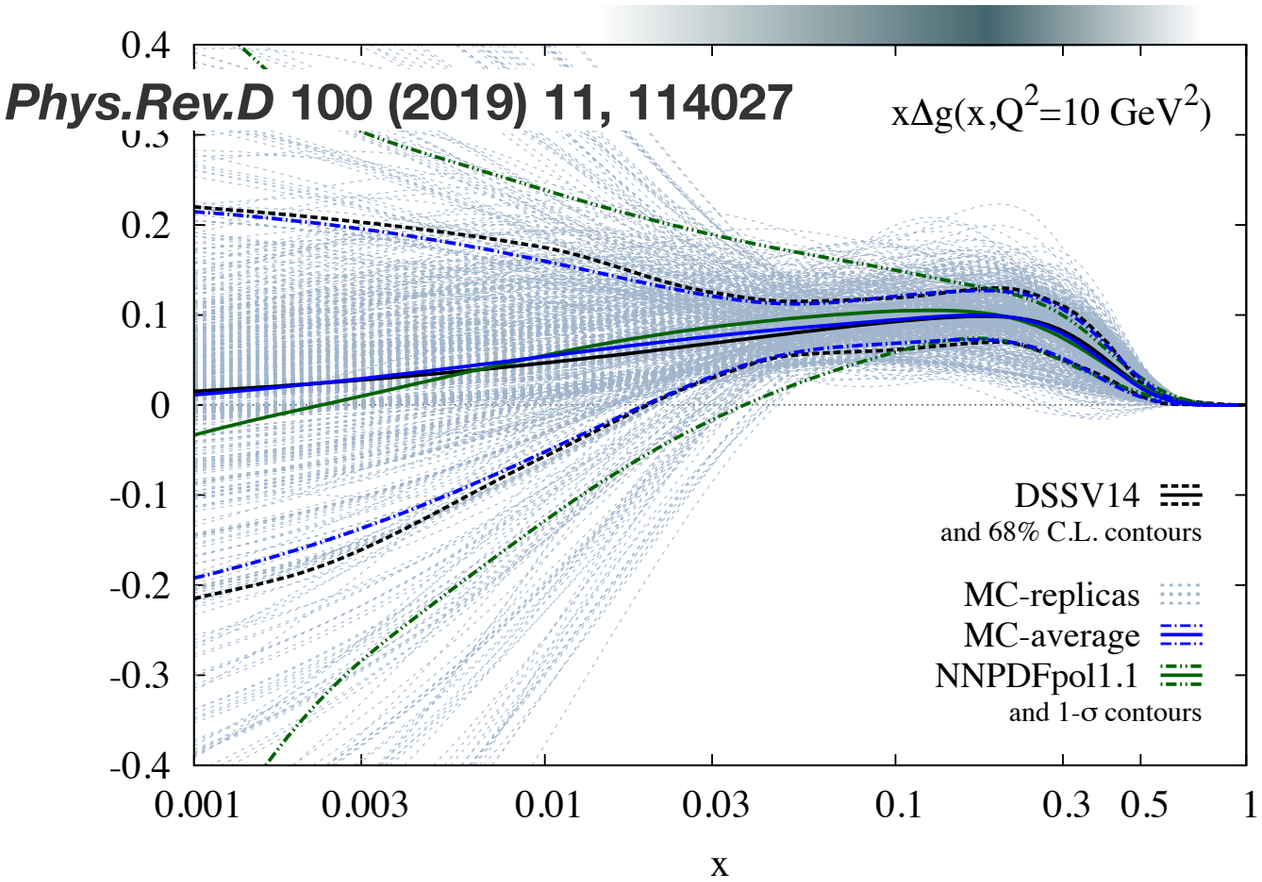


~1%

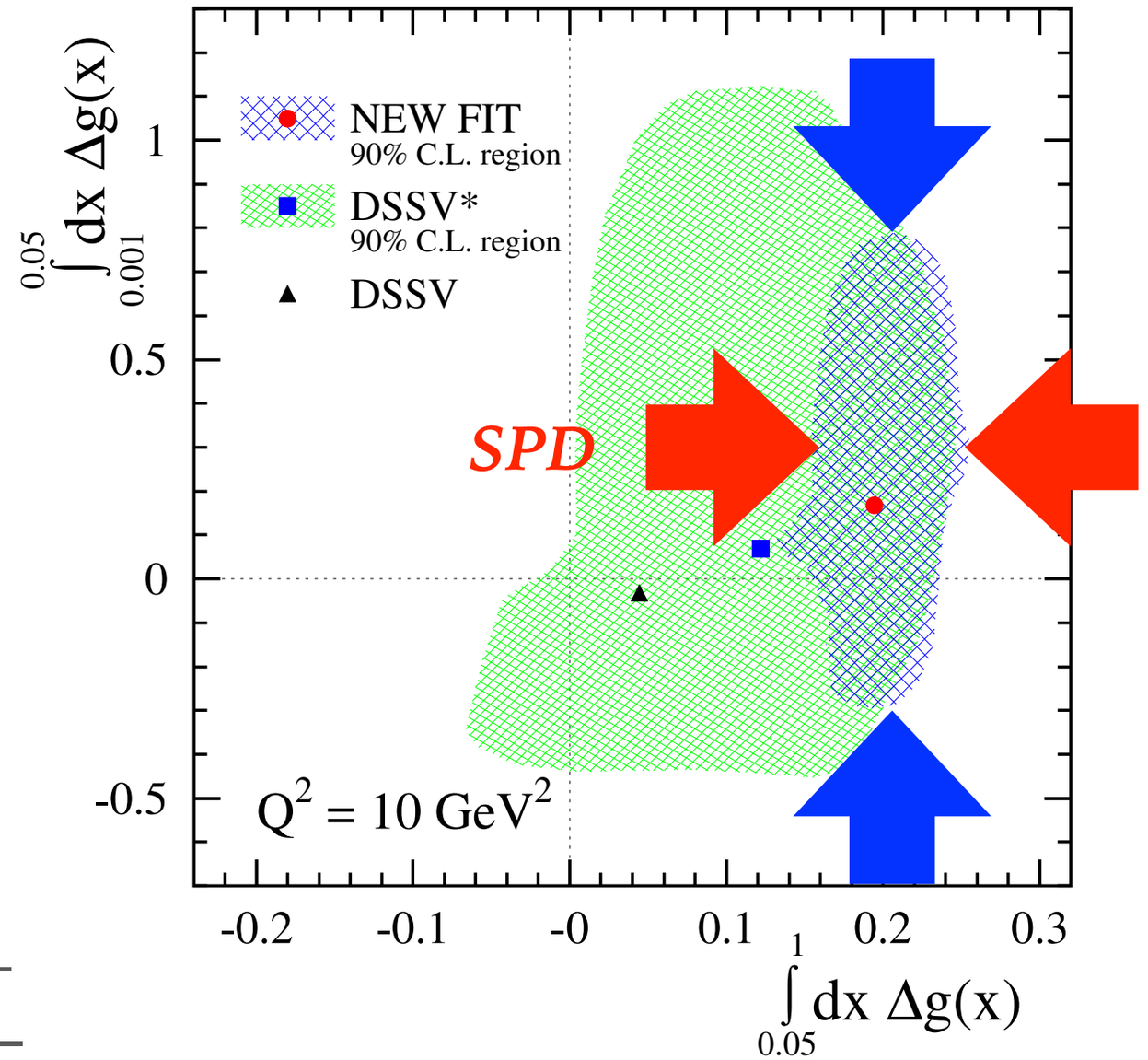


GLUON HELICITY FUNCTION Δg(x)

accessible with SPD



Phys.Rev.Lett. 113 (2014) 1, 012001 *EIC*

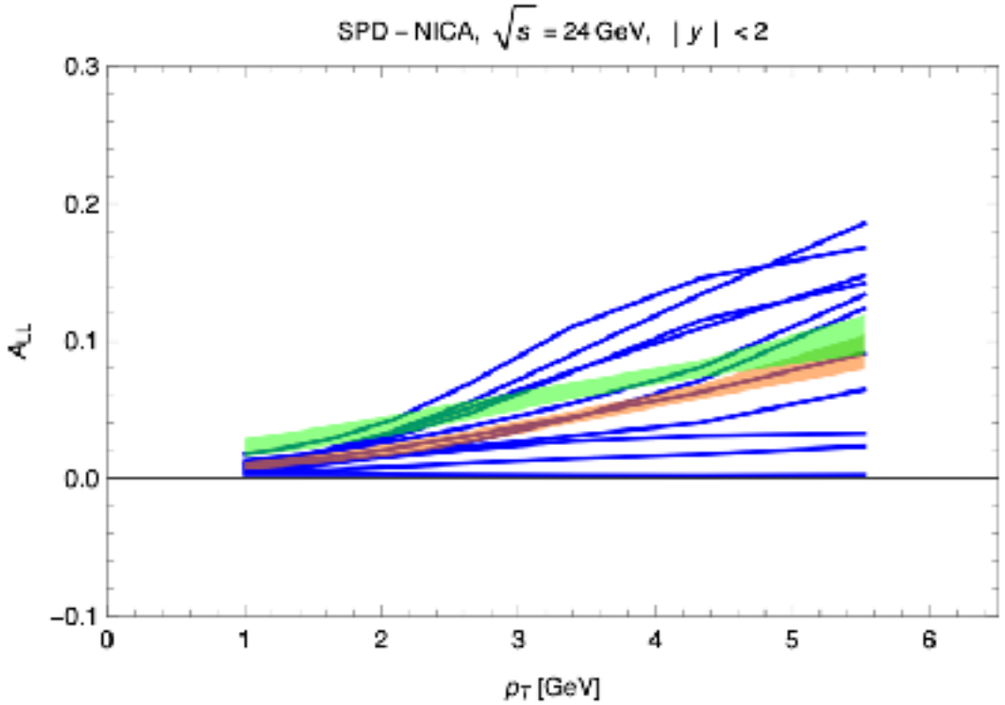


SPD could help to reduce uncertainty of ΔG at large x

$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}}$$

$$A_{LL}^{c\bar{c}} \approx \frac{\Delta g(x_1)}{g(x_1)} \otimes \frac{\Delta g(x_2)}{g(x_2)} \otimes \hat{a}_{LL}^{gg \to c\bar{c}X} \qquad A_{LL}^{\gamma} \approx \frac{\Delta g(x_1)}{g(x_1)} \otimes A_{1p}(x_2) \otimes \hat{a}_{LL}^{gq(\bar{q}) \to \gamma q(\bar{q})} + (1 \leftrightarrow 2)\,.$$

GLUON HELICITY FUNCTION Δg(x) : EXPECTATIONS FOR A_{LL}



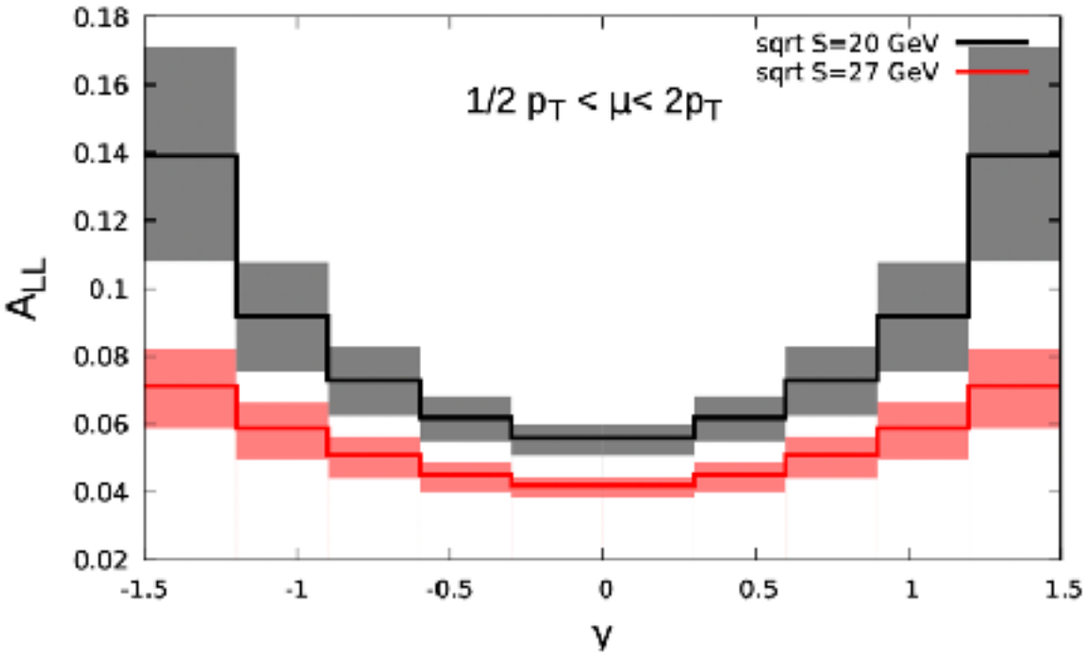
$gg \rightarrow J/\psi g$

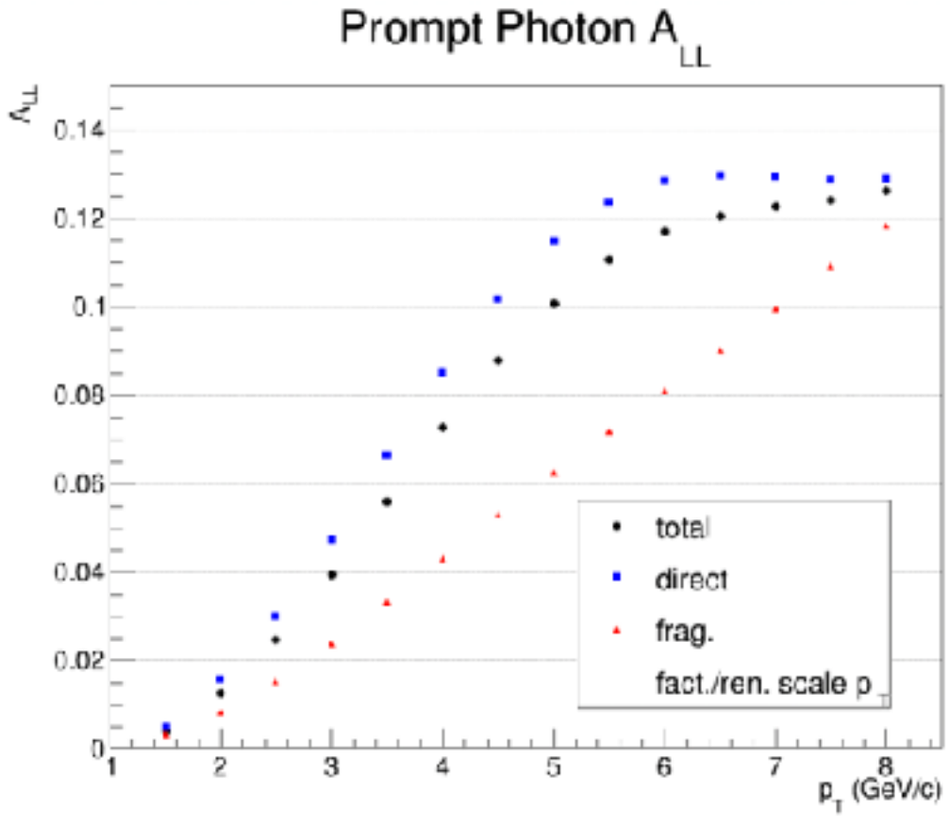
M. Nefedov

W. Vogelsang

A. Shipilova

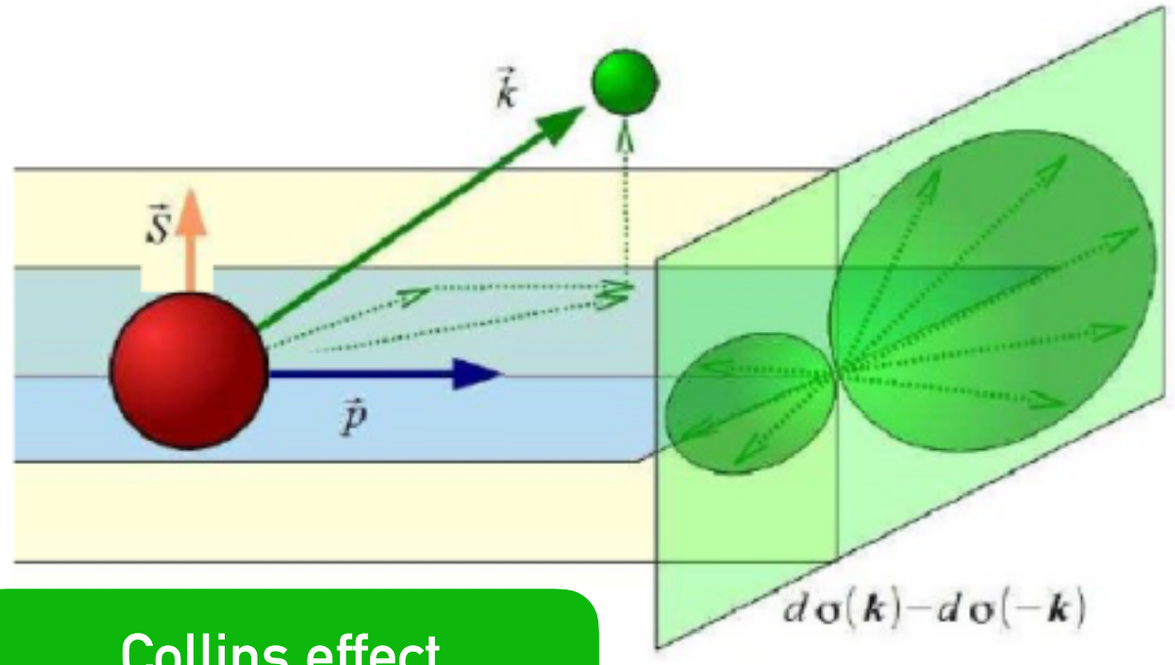
$qg \rightarrow q\gamma$





GLUON-INDUCED TMD EFFECTS : GLUON SIVERS FUNCTION $\Delta^g_N(x,k_T)$

***Sivers effect**: left-right asymmetry of unpolarized k_T distribution in transversely polarized nucleon*

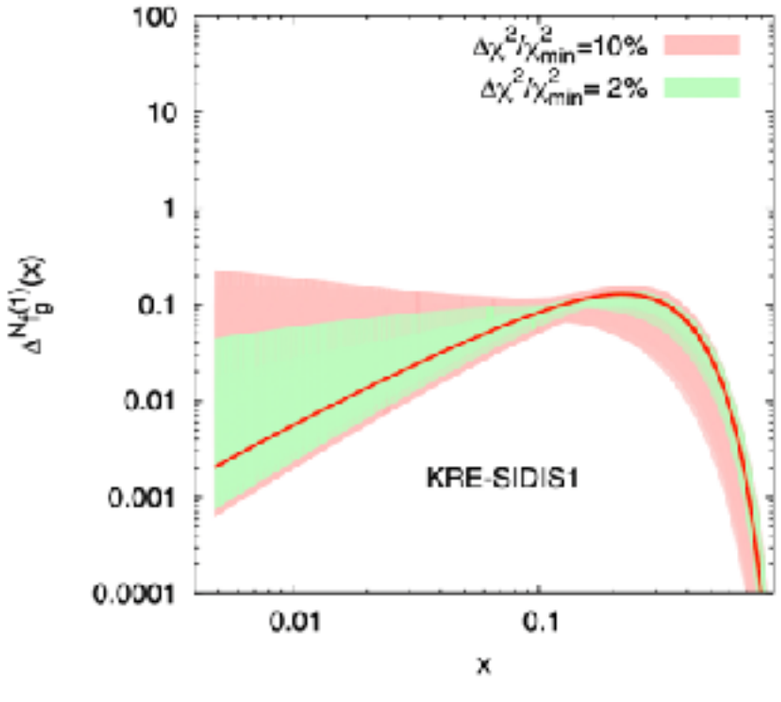


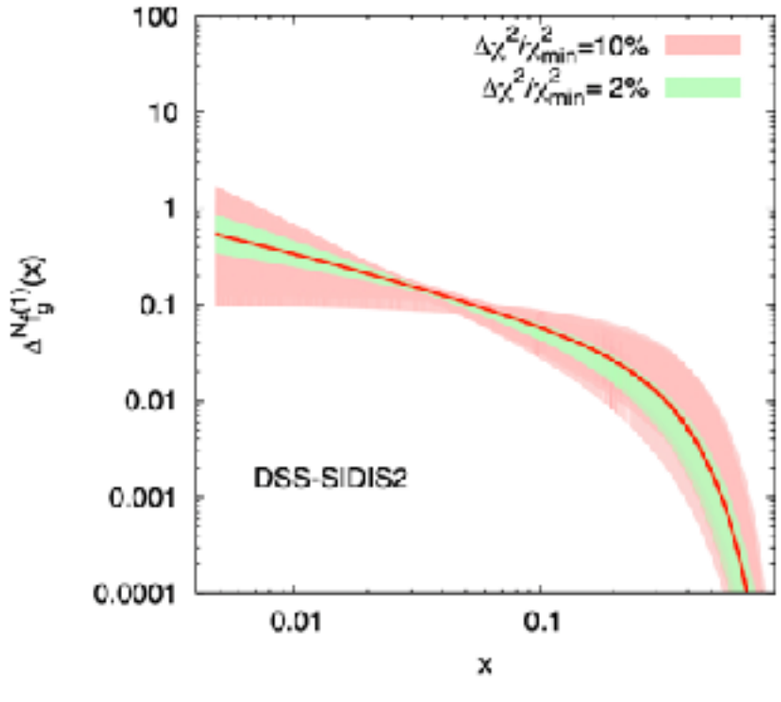
Sivers effect

A_N

Collins effect

- due to fragmentation of polarized quark

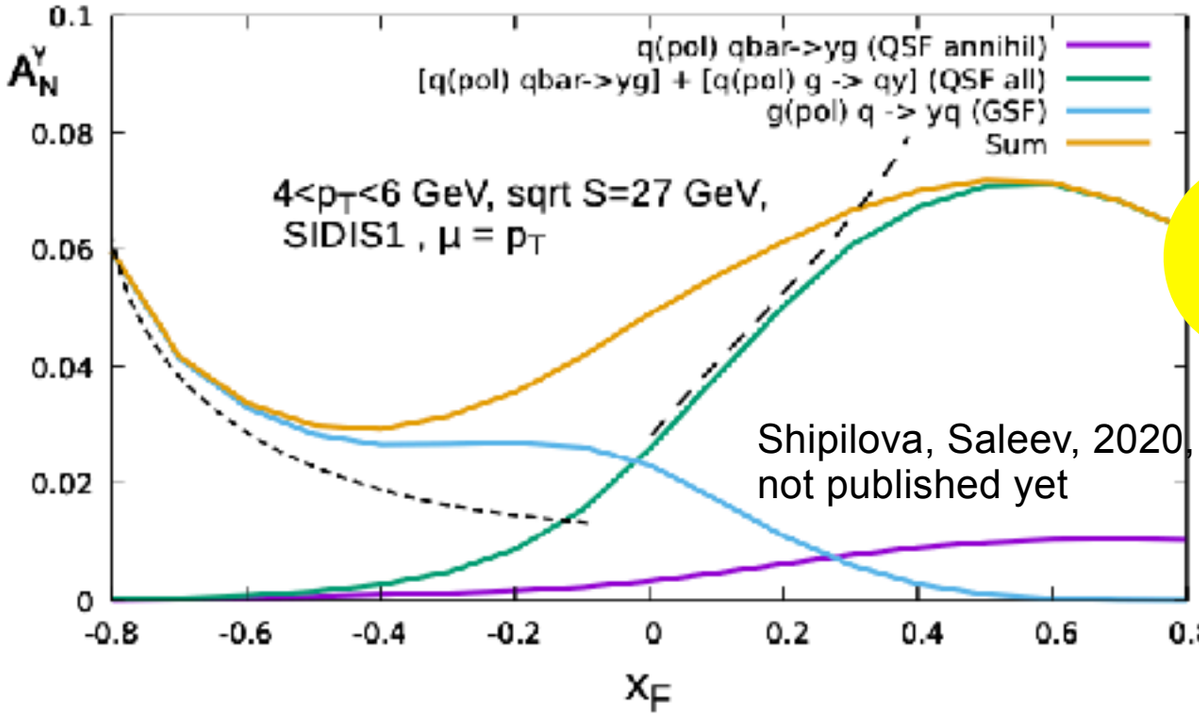




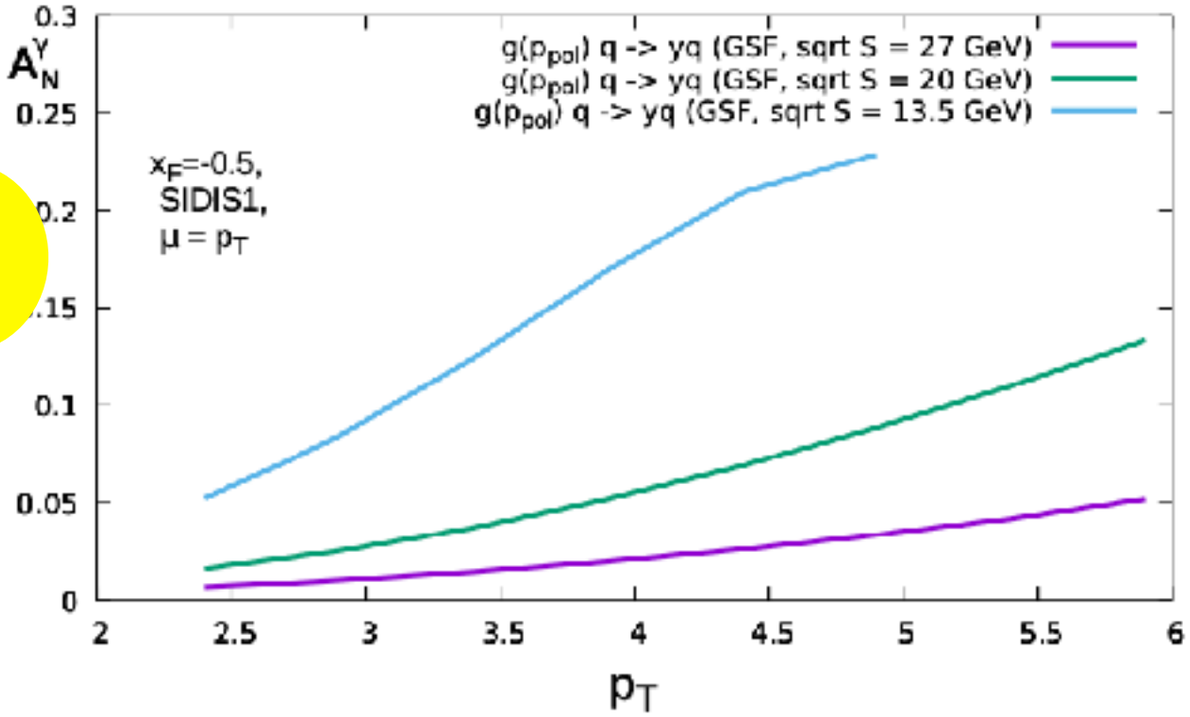
Collins effect in the first approximation is absent for chamonia and prompt-photon production:

GLUON-INDUCED TMD EFFECTS: EXPECTATIONS FOR A_N

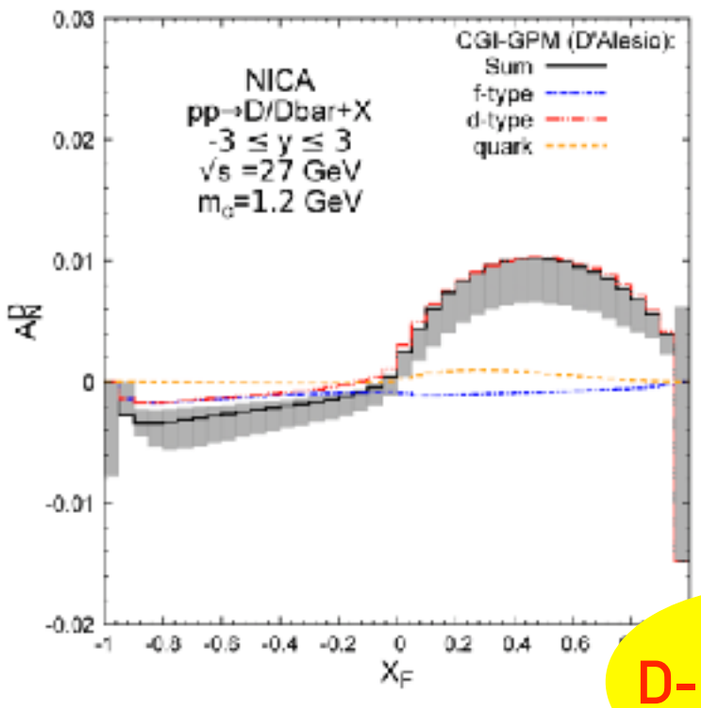
Sivers effect contribution

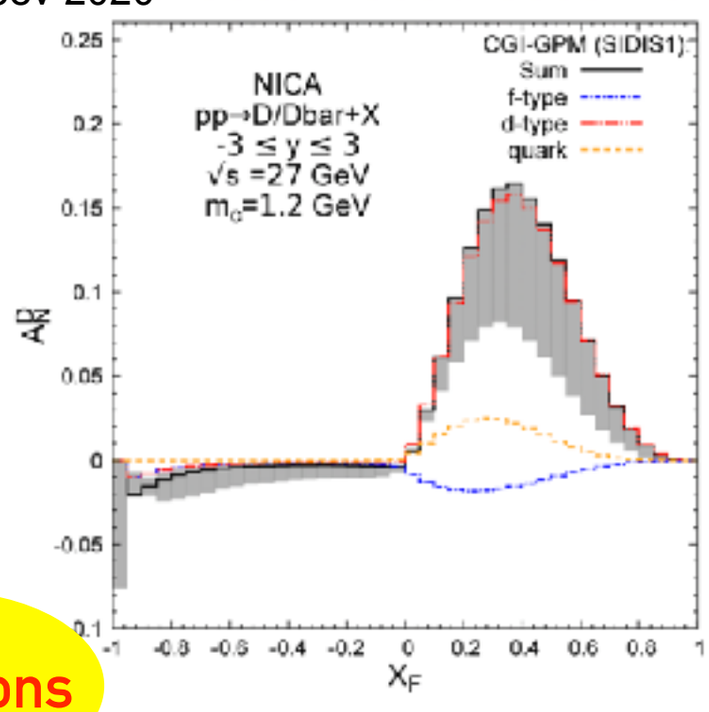


Y

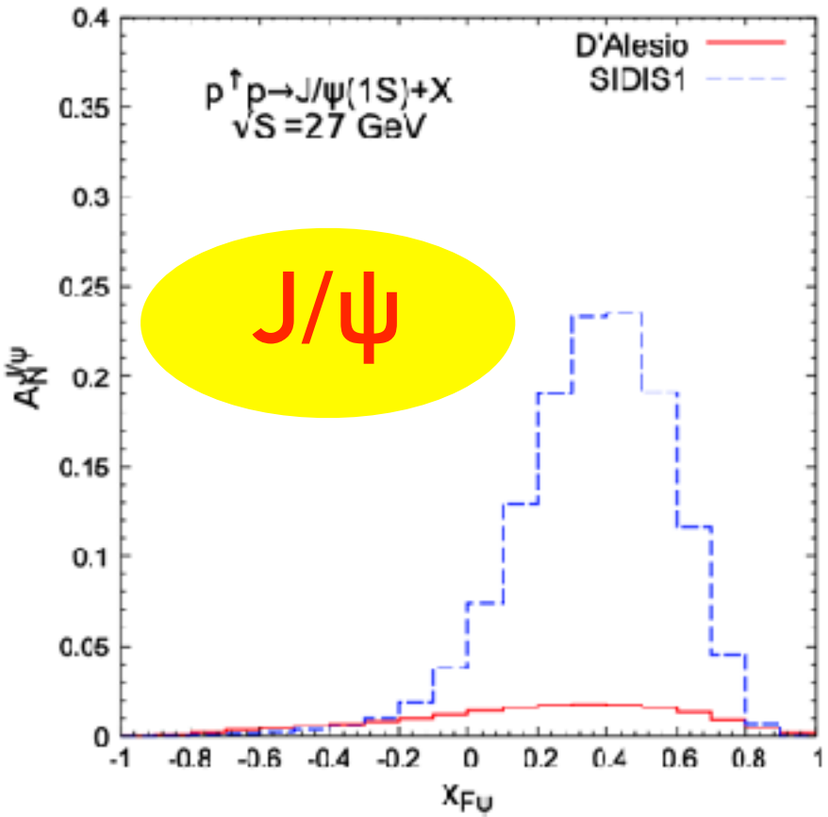


Saleev 2020





D-mesons



GLUON-INDUCED TMD EFFECTS : BOER-MULDERS FUNCTION $h_1^{\perp g}(x,k_T)$

$gg \to D\bar{D}, \gamma\gamma, J/\psi\gamma, \ldots$

The hadronic cross section can be written with corrections of order $\mathcal{O}(\infty/\mathcal{S})$ in the form [D. Boer, P. Mulders, C. Pisano, 2008]

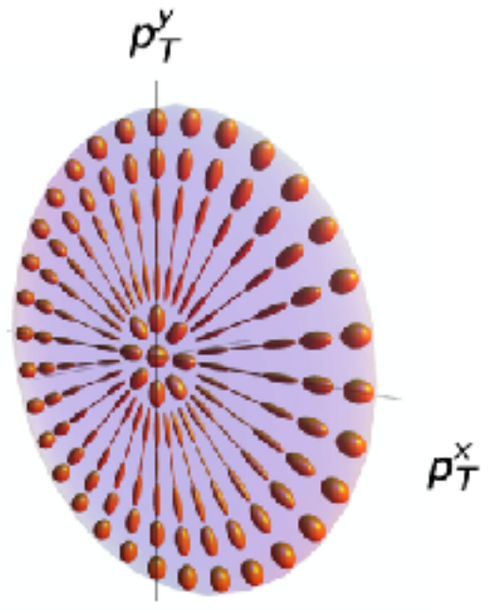
$$\frac{d\sigma(pp\to D\bar{D}X)}{d\eta_1 d\eta_2 d^2k_{1T} d^2k_{2T}} = \frac{\alpha_S}{SK_T^2}\left[A(Q_T^2) + B(Q_T^2)Q_T^2\cos 2(\phi_T - \phi_\perp) + C(Q_T^2)Q_T^4\cos 4(\phi_Q - \phi_K)\right]$$

$$\vec{Q}_T = \vec{k}_{1T} + \vec{k}_{2T}, \qquad \vec{K}_T = (\vec{k}_{1T} - \vec{k}_{2T})/2$$

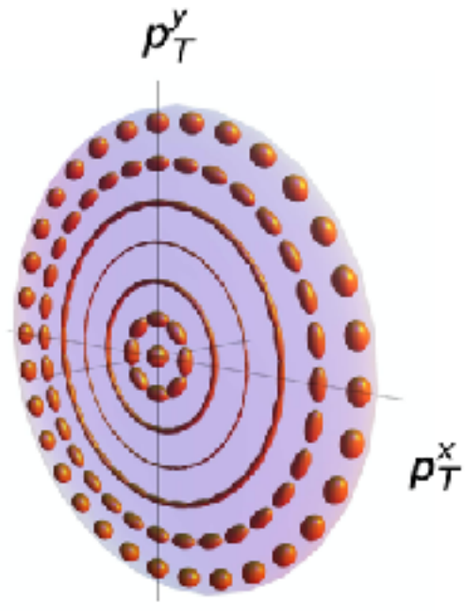
$$A: \quad f_1^q \otimes f_1^{\bar{q}},\ f_1^g \otimes f_1^g\,,$$

$$B: \quad h_1^{\perp q} \otimes h_1^{\perp \bar{q}},\ \frac{M_Q^2}{M_\perp^2} f_1^g \otimes h_1^{\perp g}\,,$$

$$C: \quad h_1^{\perp g} \otimes h_1^{\perp g}\,.$$

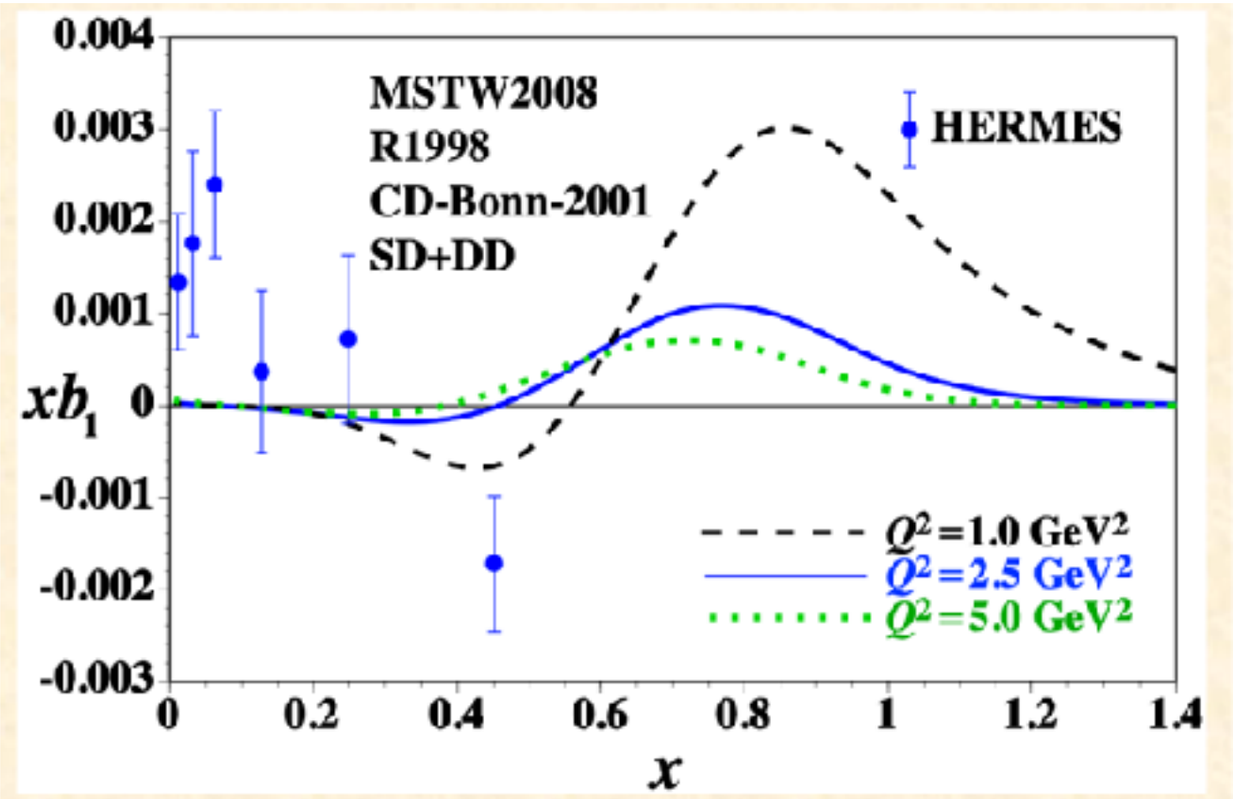


$h_1^{\perp g} > 0$

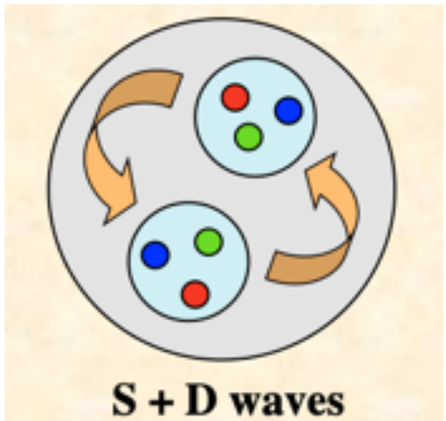


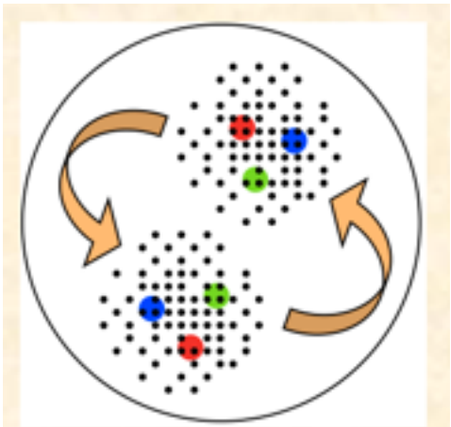
$h_1^{\perp g} < 0$

UNPOLARIZED GLUONS IN DEUTERON AT HIGH x



S. Kumano





$$|6q\rangle = c_1|NN\rangle + c_2|\Delta\Delta\rangle + c_3|CC\rangle$$

hidden color

up to 90% at some models!

G. A. Miller, Phys.Rev. C89 (2014) no.4, 045203

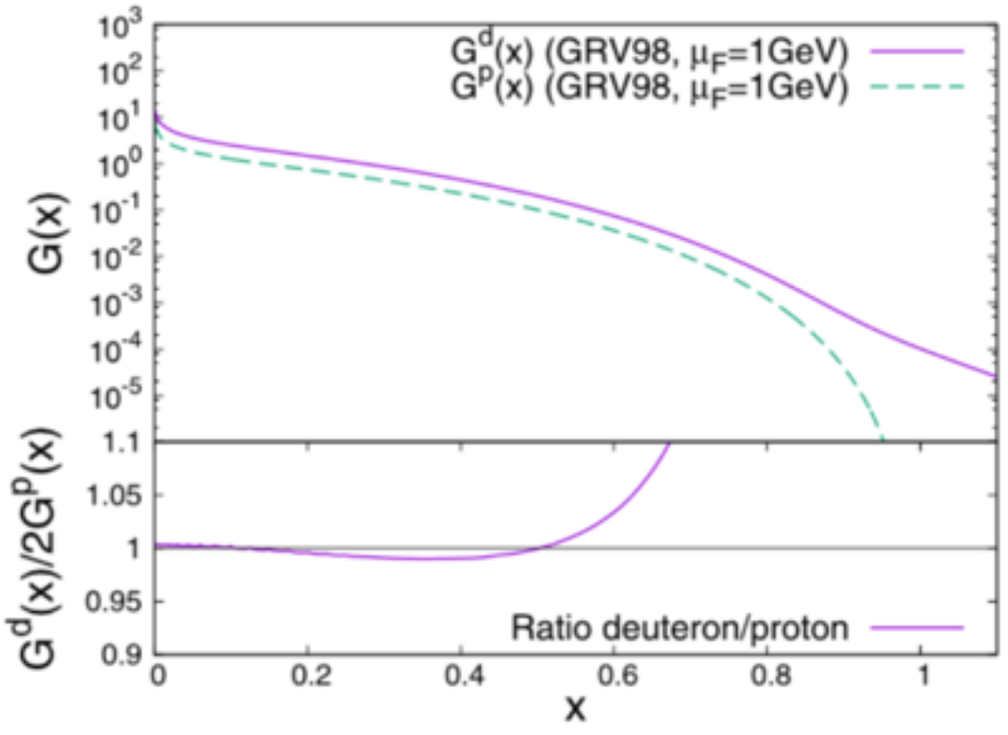
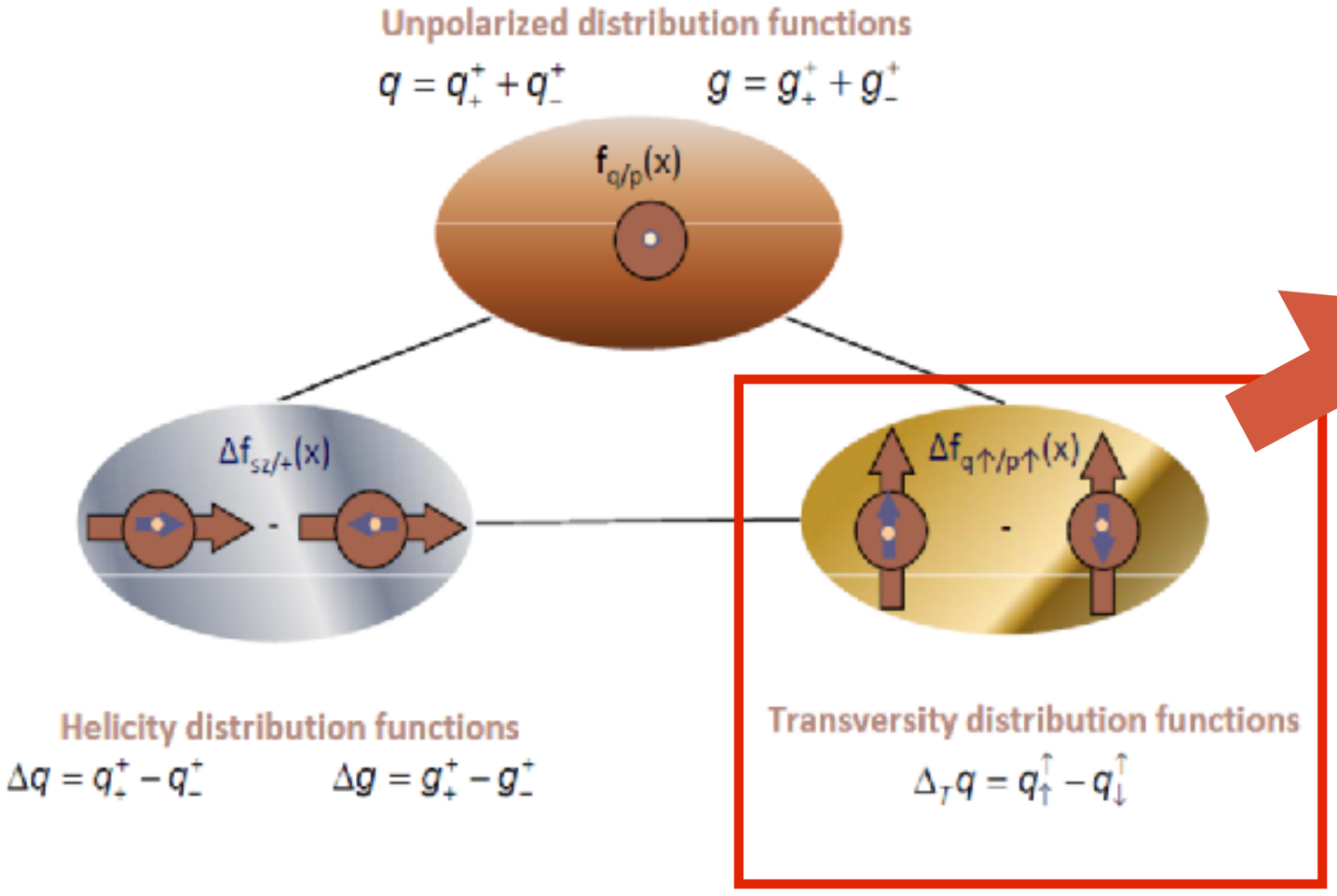


Fig. 6. Gluon PDF in the deuteron and in the nucleon.

Phys.Lett. B783 (2018) 287-293

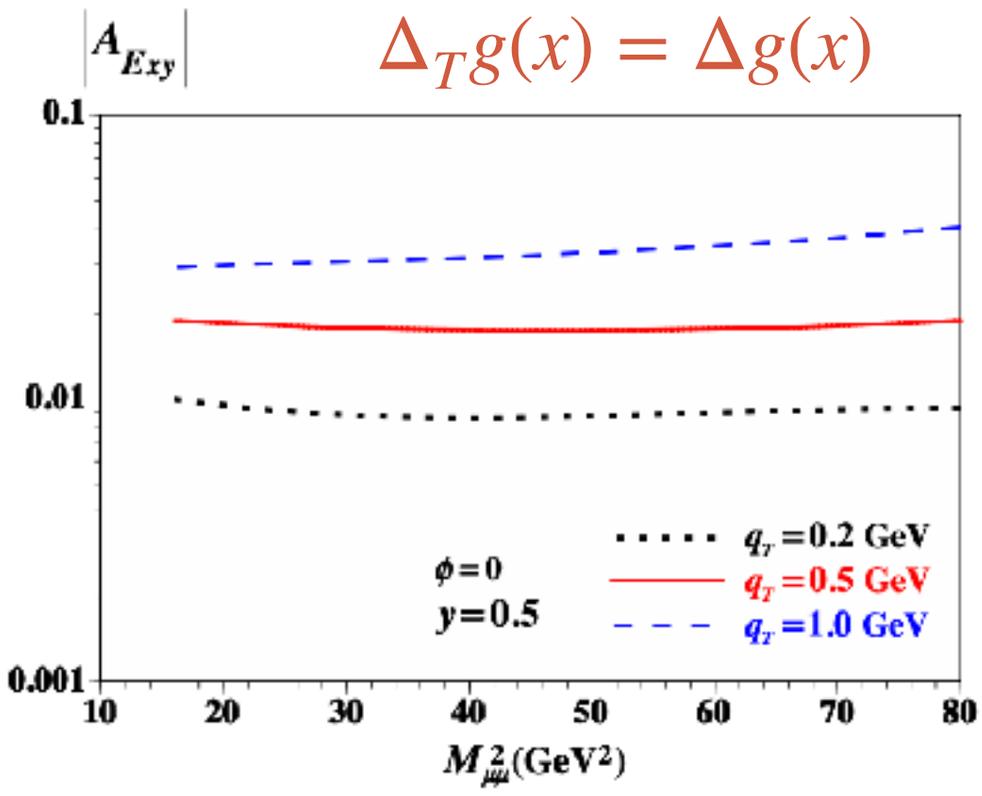
GLUON TRANSVERSITY $\Delta g_T(x)$ IN DEUTERON



Transversity function is related to spin-flip amplitude but $\Delta s=2$ is impossible in LO for spin-1/2 hadron.

But it nonzero gluon transversity is possible already in LO in deuteron due to non-nucleonic gluon component! It could be accessed via double transverse spin asymmetry!

Sh. Kumano for DY:
$\Delta_T g(x) = \Delta g(x)$

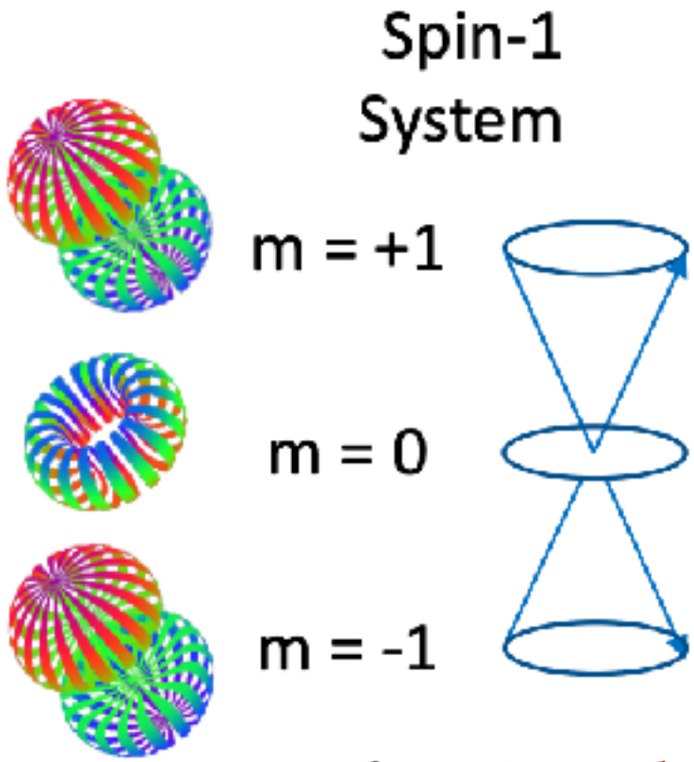


RATES FOR MAIN PROBES

Probe	$\sigma_{27\,\mathrm{GeV}}$, nb (×BF)	$\sigma_{13.5\,\mathrm{GeV}}$, nb (×BF)	$N_{27\,\mathrm{GeV}}$, 10^6	$N_{13.5\,\mathrm{GeV}}$ 10^6
Prompt-γ ($p_T > 3$ GeV/c)	35	2	35	0.2
J/ψ	200	60		
$\to \mu^+\mu^-$	12	3.6	12	0.36
$\psi(2S)$	25	5		
$\to J/\psi\pi^+\pi^- \to \mu^+\mu^-\pi^+\pi^-$	0.5	0.1	0.5	0.01
$\to \mu^+\mu^-$	0.2	0.04	0.2	0.004
$\chi_{c1} + \chi_{c2}$	200			
$\to \gamma J/\psi \to \gamma\mu^+\mu^-$	2.4		2.4	
η_c	400			
$\to p\bar{p}$	0.6		0.6	
Open charm: $D\overline{D}$ pairs	14000	1300		
Single D-mesons				
$D^+ \to K^-2\pi^+$ ($D^- \to K^+2\pi^-$)	520	48	520	4.8
$D^0 \to K^-\pi^+$ ($\overline{D}^0 \to K^+\pi^-$)	360	33	360	3.3

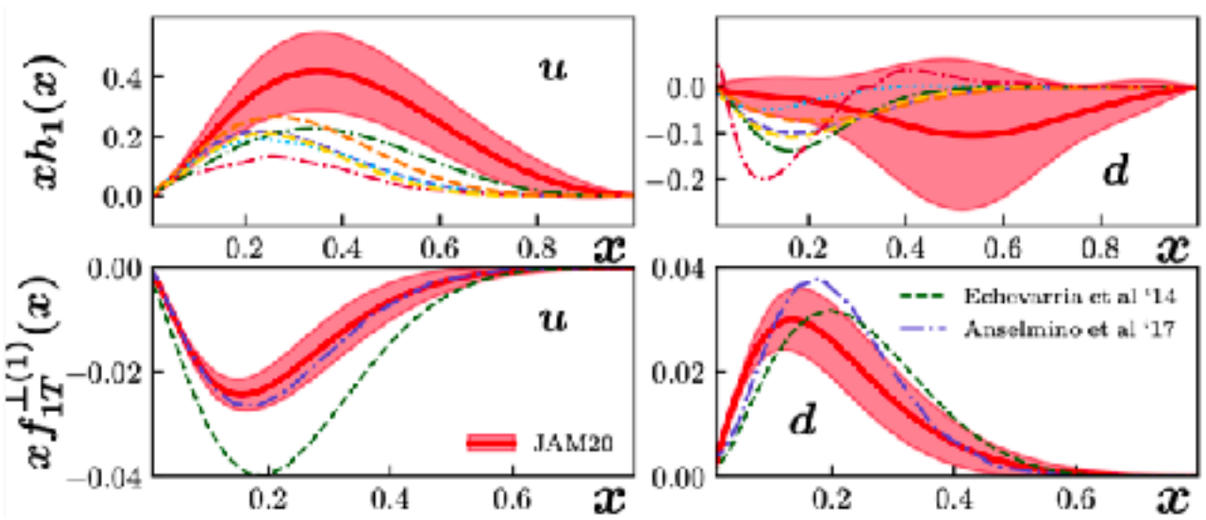
OTHER TASKS RELATED WITH THE PARTONIC STRUCTURE

Tensor structure of deuteron:

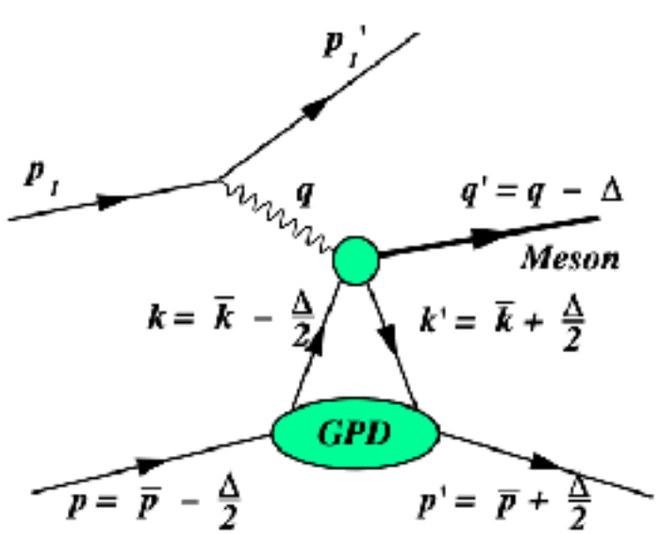


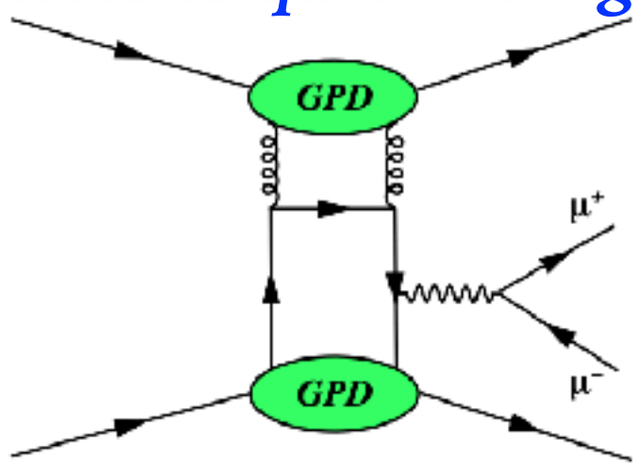
New structure functions: b_1, b_2, b_3, b_4

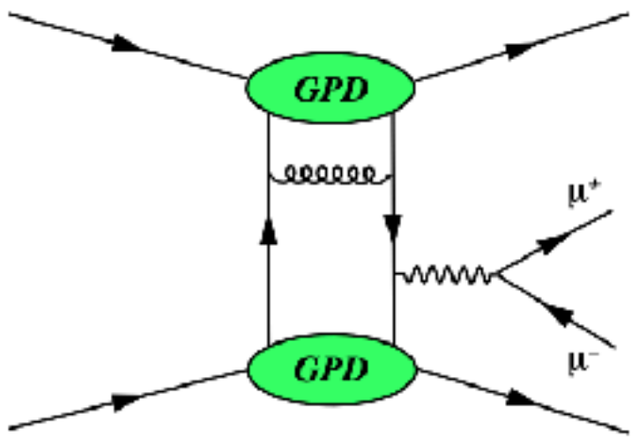
STSA with light hadrons — contribution to global fit of quark TMDs



Access to quark and gluon GPDs







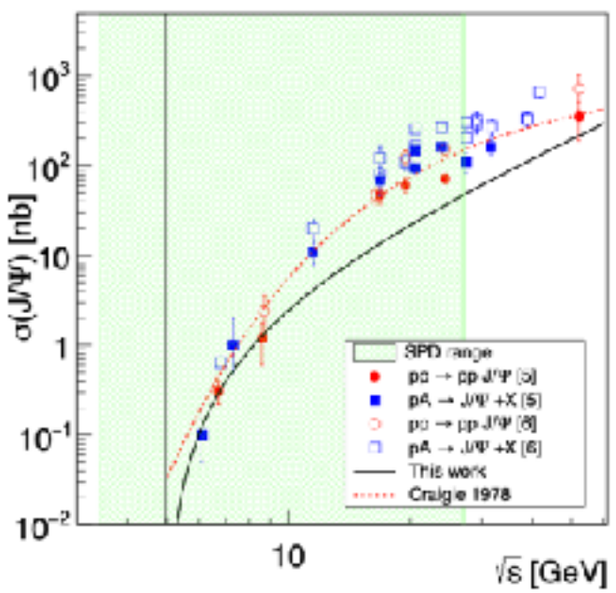
arXiv:2102.08477

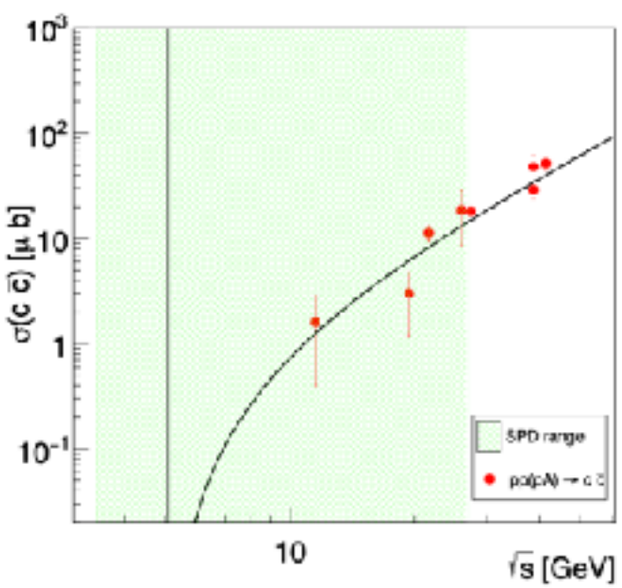
PHYSICS OF THE FIRST STAGE OF SPD RUNNING

Non-perturbative QCD — *Perturbative QCD*

$\sqrt{s}$

- Spin effects in p-p, p-d and d-d elastic scattering
- Spin effects in hyperons production
- Multiquark correlations $pp \to (6q)^* \to N\,N\,Mesons,$
- Dibaryon resonances
- Physics of light and intermediate nuclei collision
- Exclusive reactions
- Hypernucei $dd \to K^+\,K^+\,{}^{4}_{\Lambda\Lambda}\mathrm{n},$
- Open charm and charmonia near threshold





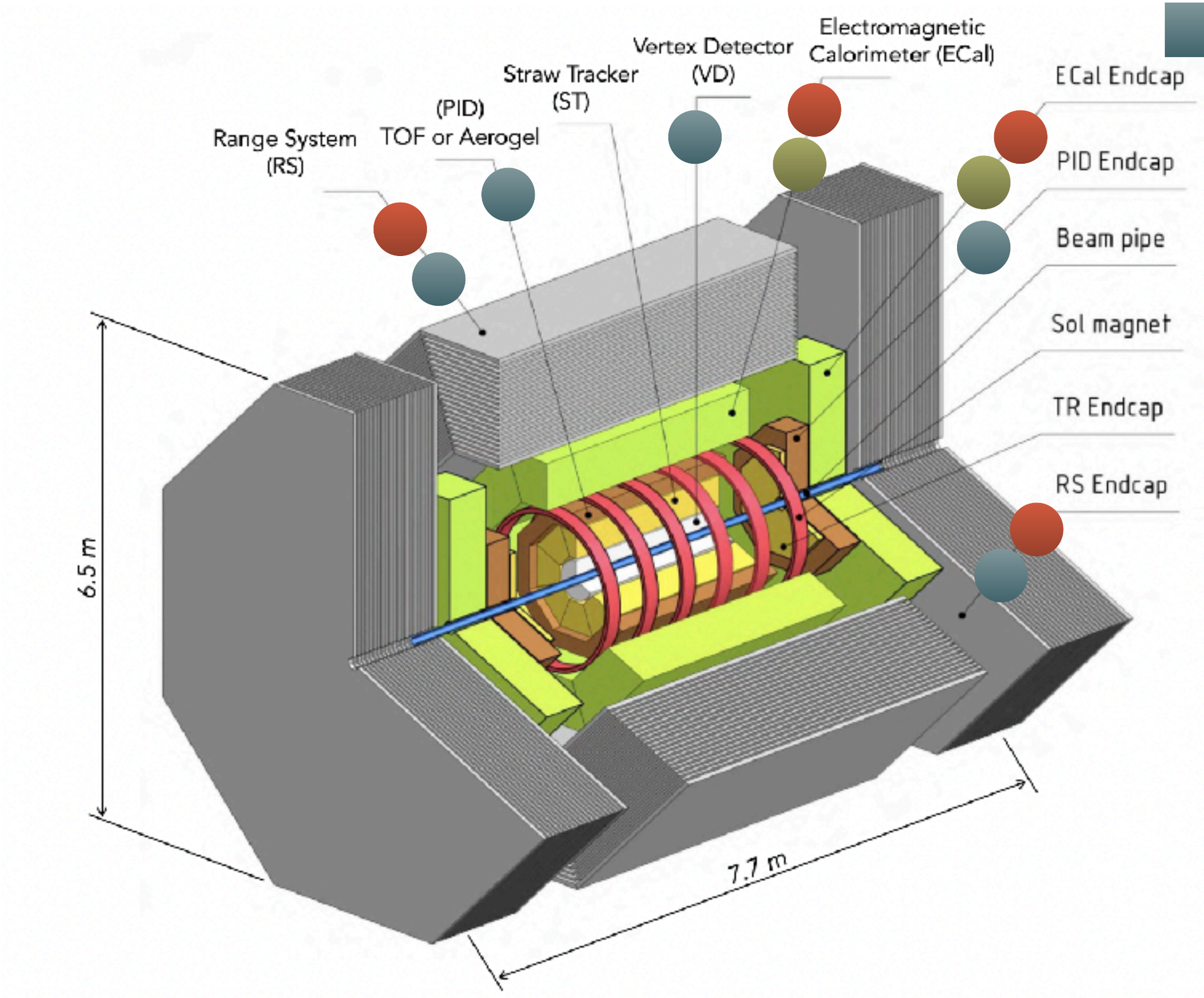
- Auxiliary measurements for astrophysics
- …

SPD DETECTOR

Charmonia

Prompt photons

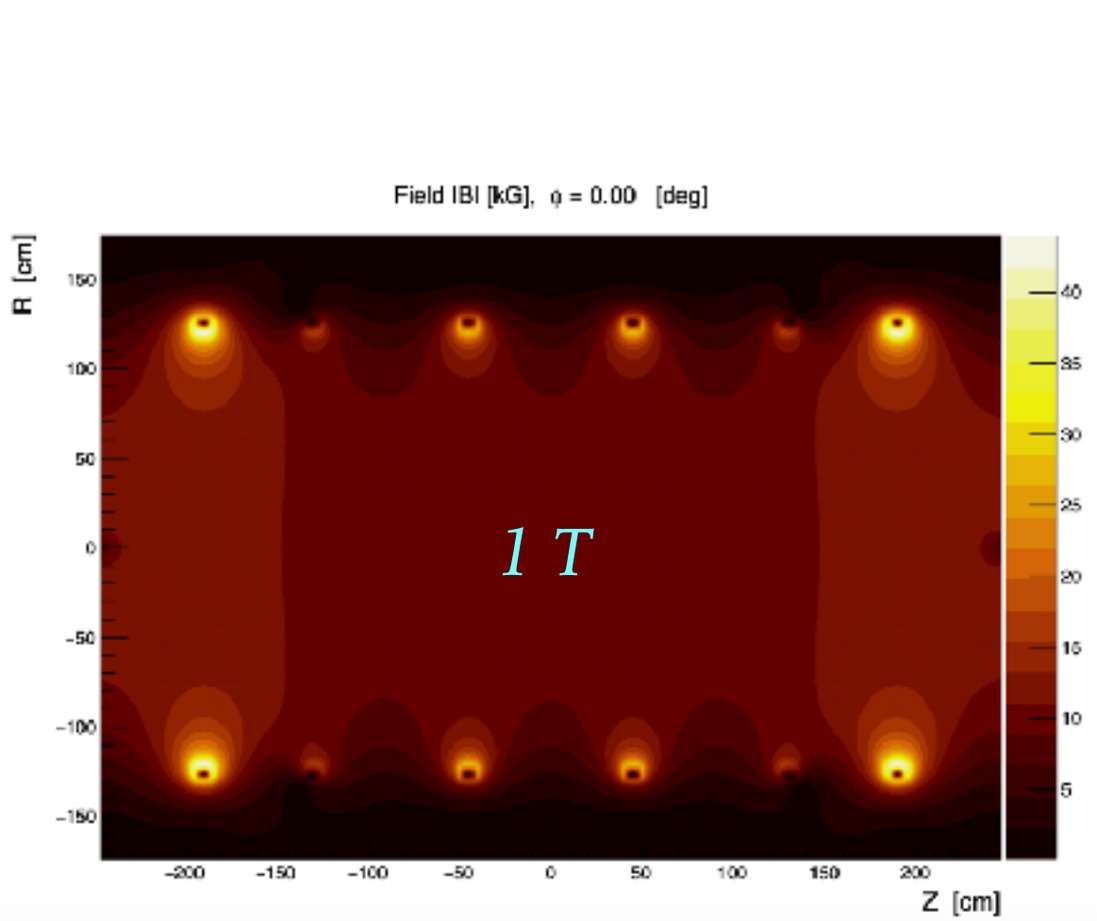
Open charm

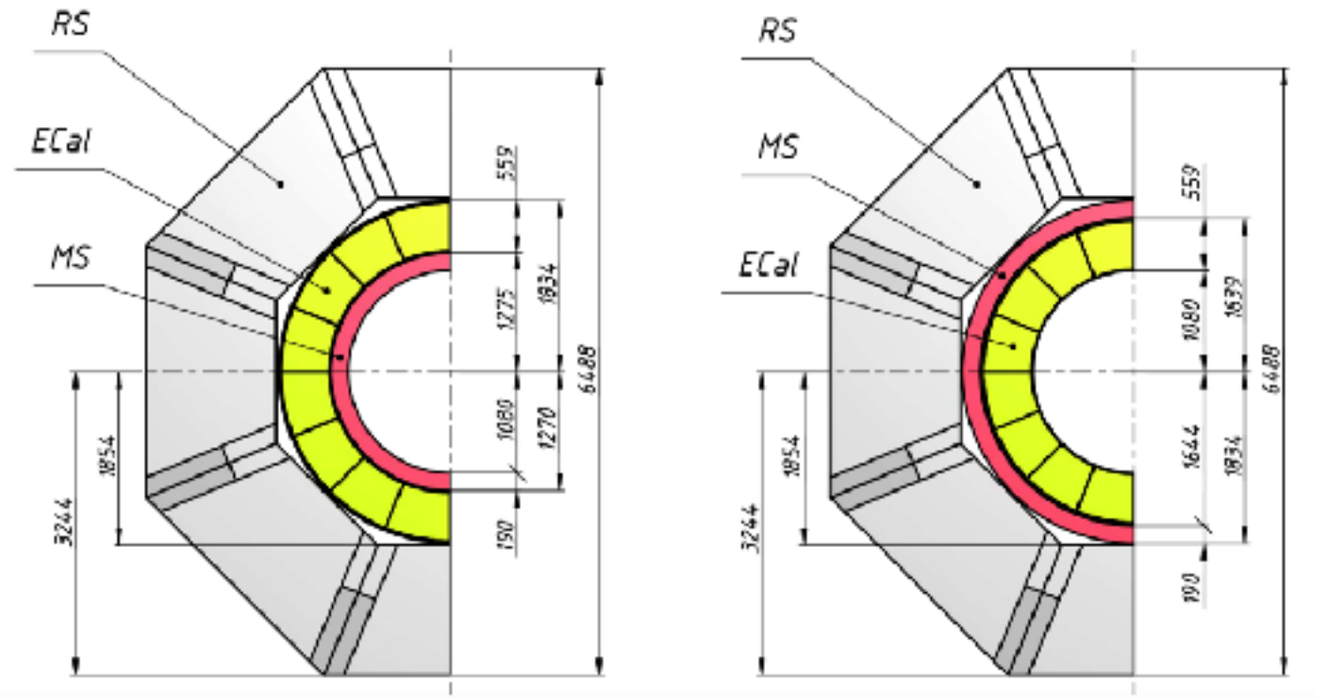


MAGNETIC SYSTEM

6 superconductive solenoidal coils inside the ECAL:

- *compact*
- *1 T at the beam axis*
- *Z-optimization*





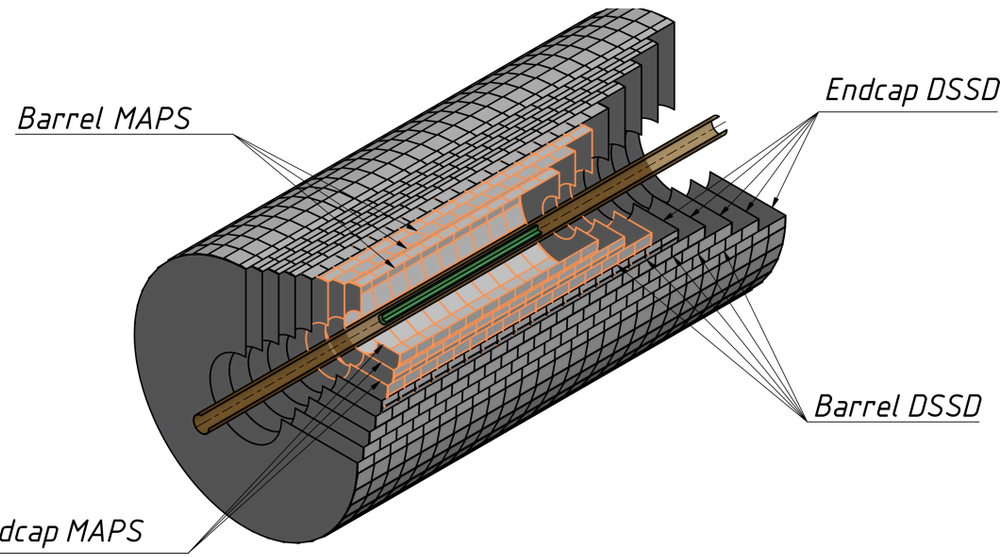
Still 2 options

TRACKING SYSTEM

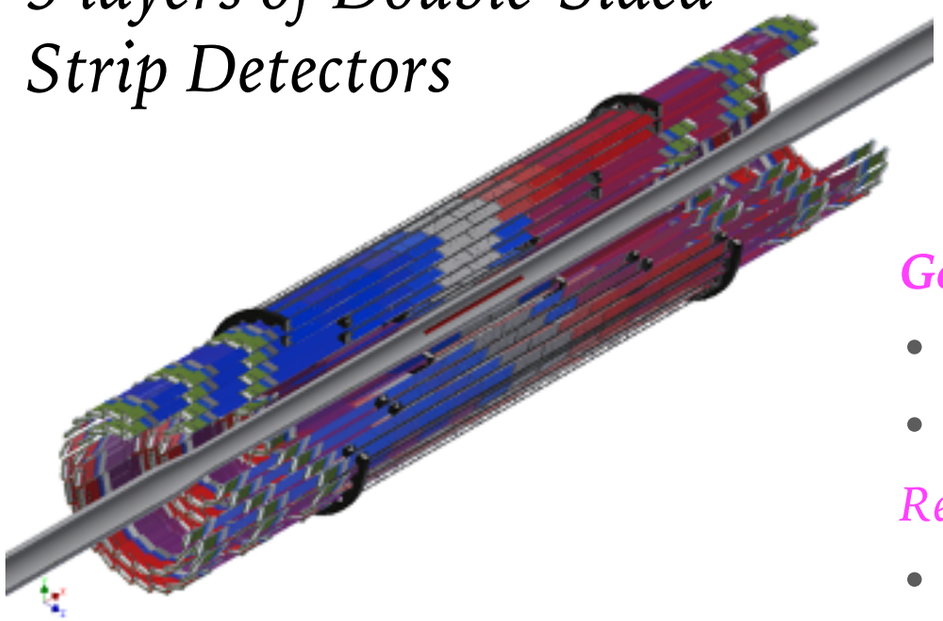
3 internal layers in barrel replaced by MAPS

Vertex Detector

Two options:



5 layers of Double-Sided Strip Detectors



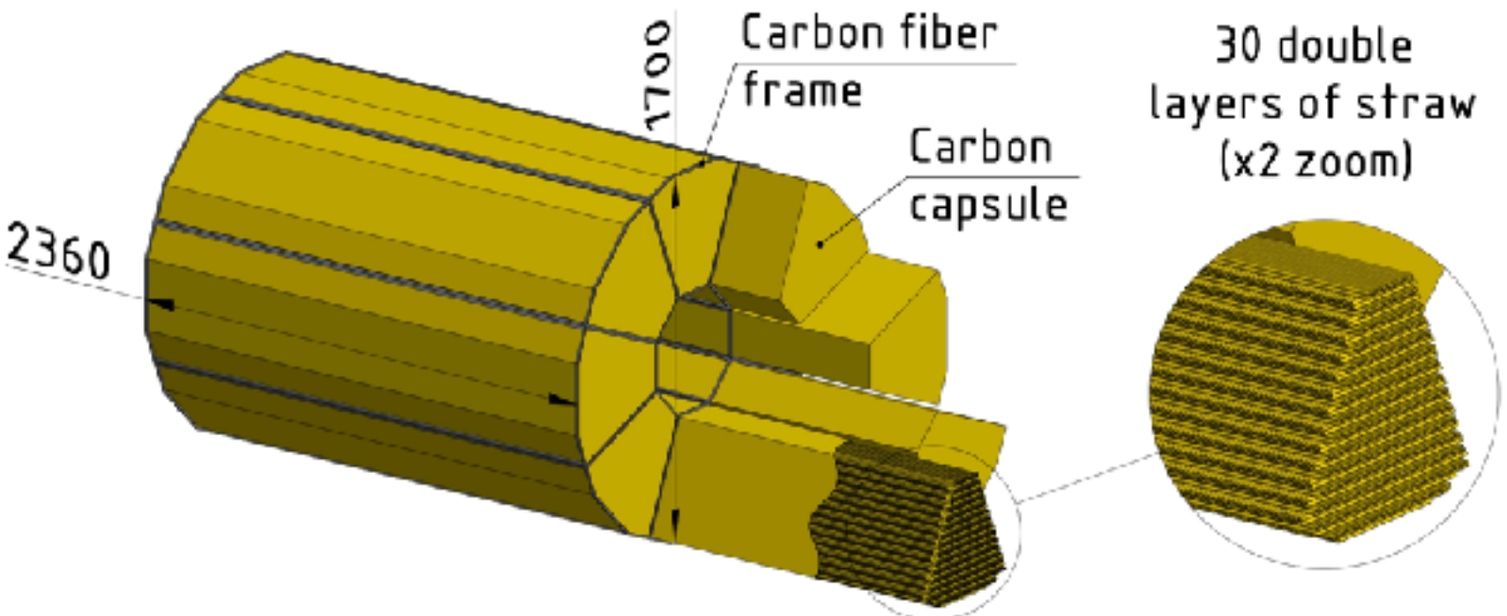
Goals:

- *Reconstruction of secondary vertices for D-mesons decay*
- *Participation in track reconstruction and momentum measurement*

Requirements:

- *Spatial resolution <100 μm*
- *Low material budget*
- *Has to be installed as close as possible to the IP*

Straw tracker



Goals:

- *Track reconstruction and momentum measurement*
- *Participation in PID via dE/dx measurement*

Requirements:

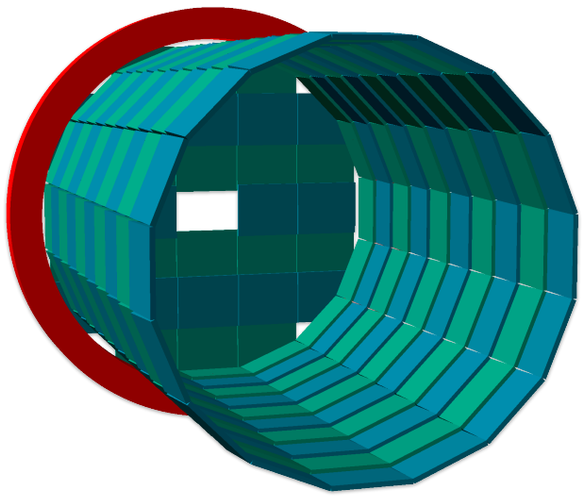
- *Spatial resolution ~150 μm*
- *Low material budget*
- *Operation in magnetic field of about 1 T*

some R&D is still needed

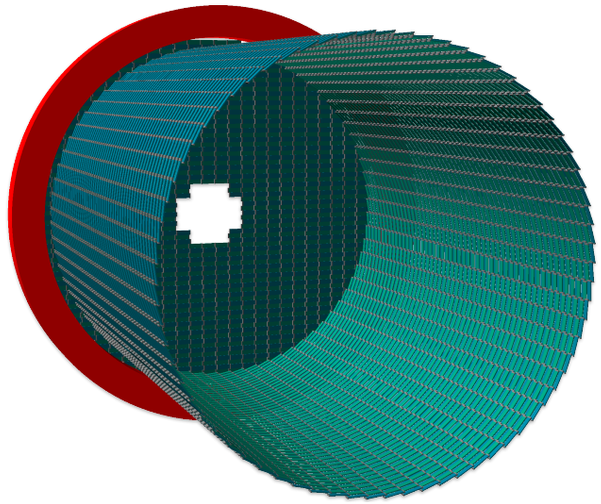
PARTICLE IDENTIFICATION SYSTEM

TOF system

mRPC-based



Scintillator-based



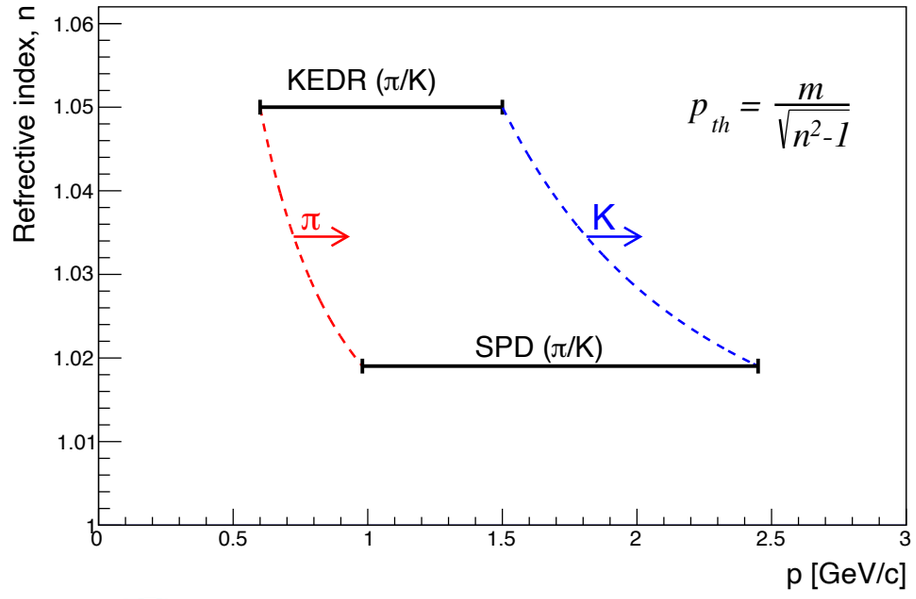
Goals:

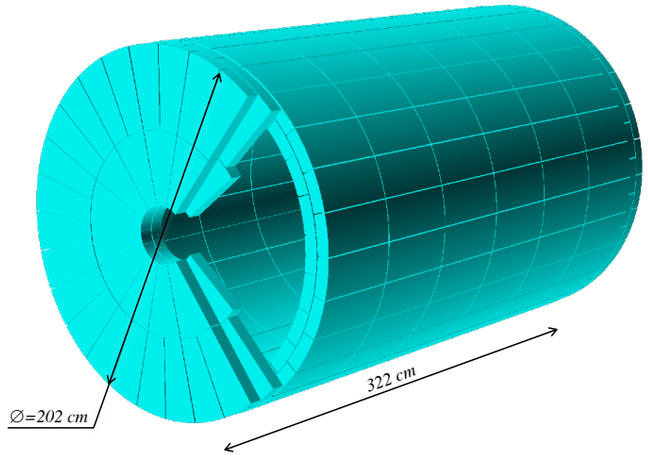
- *π/K separation up to ~1.5 GeV*
- *K/p separation*
- *t_0 determination*

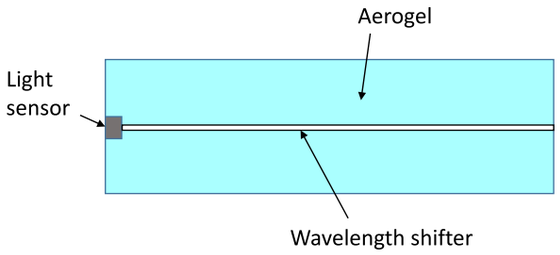
Requirements:

- *Time resolution ~60-70 ps*

Aerogel-based PID







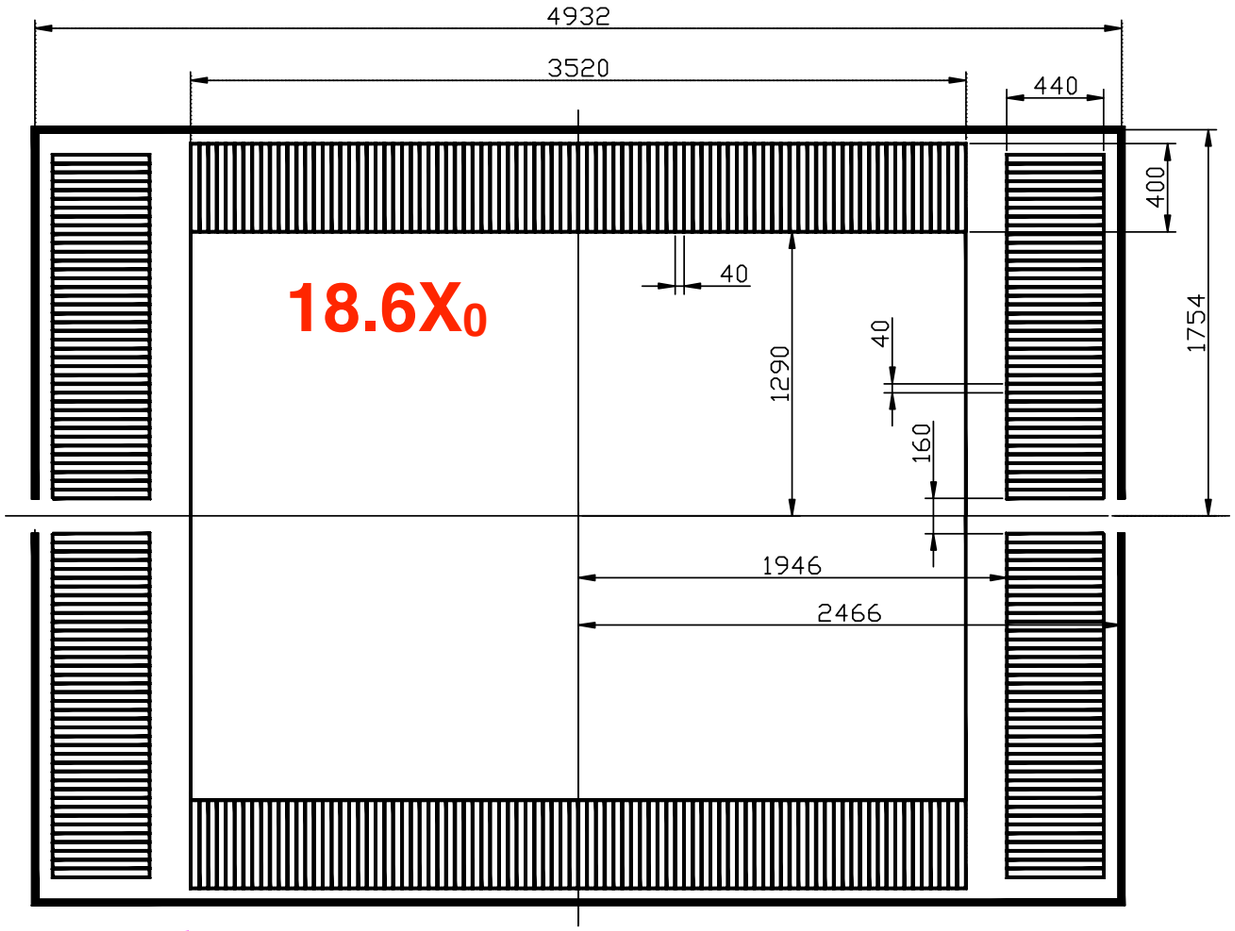
Goals:

- *π/K separation up to 2.5 GeV range*

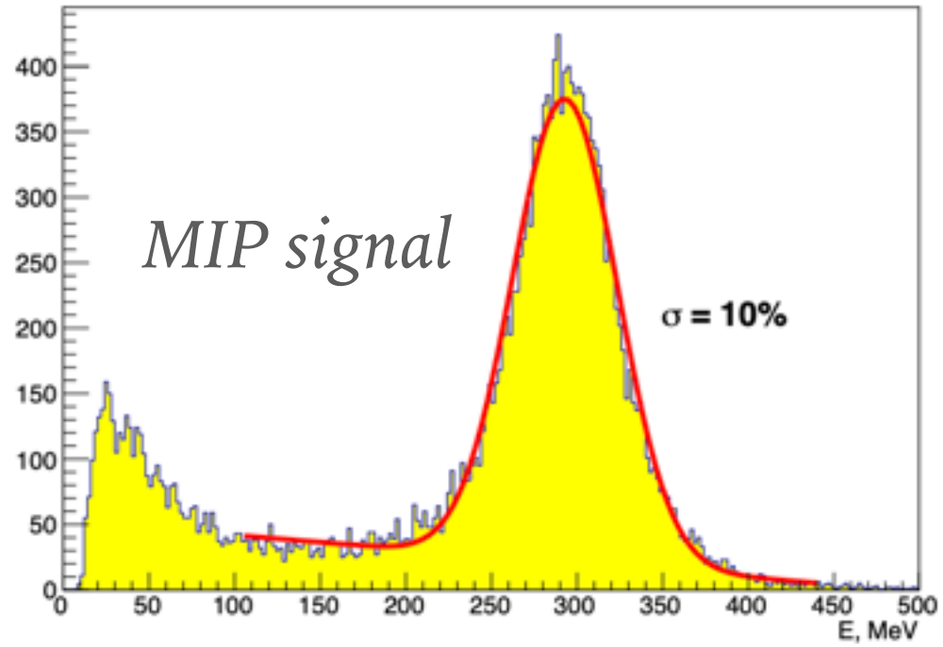
Requirements:

- *We should have enough light!*

ELECTROMAGNETIC CALORIMETER



"Shashlyk"-type: 200 layers of scintillator (1.5 mm) and Pb (0.5 mm)



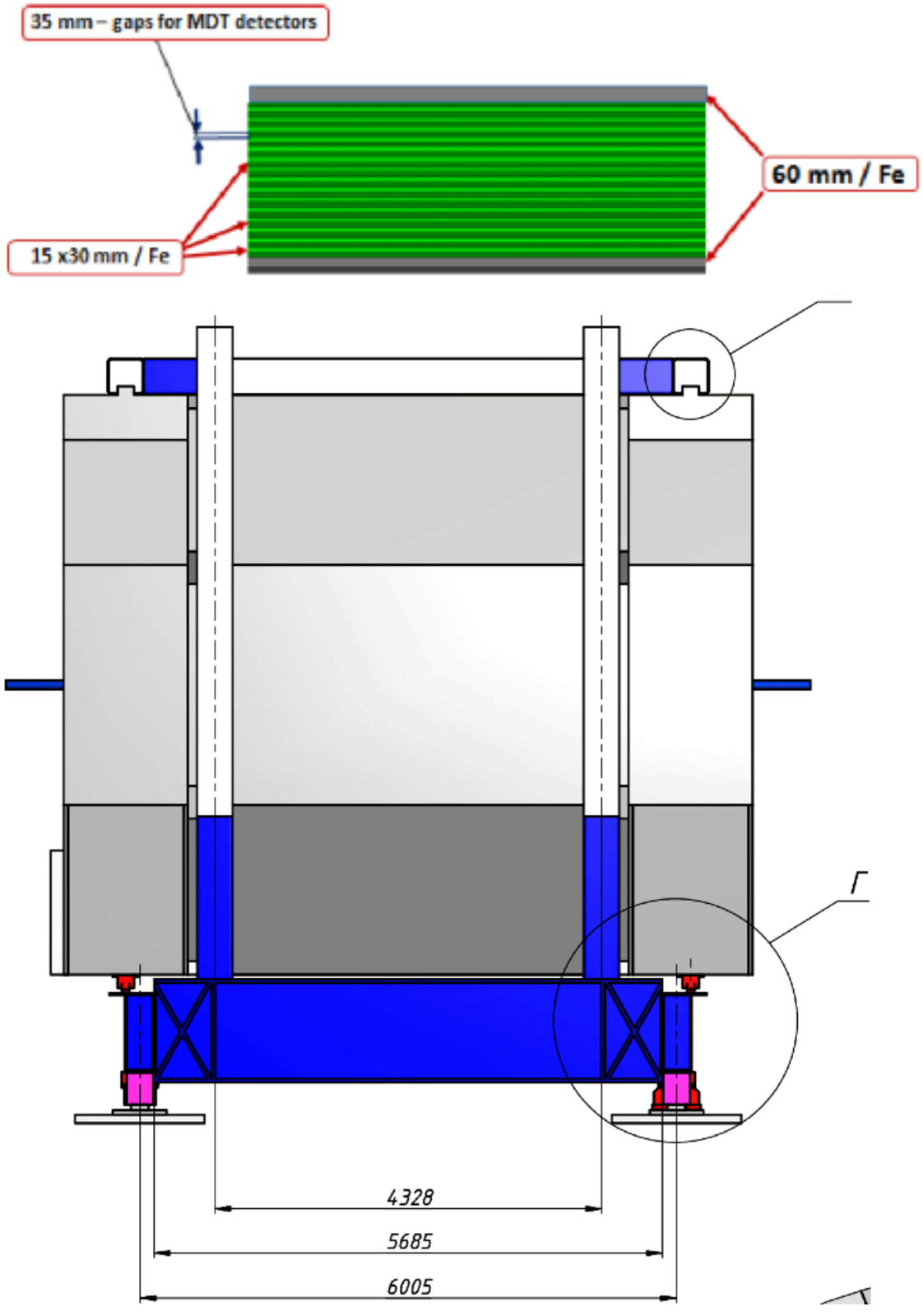
Goals:

- *Detection of prompt photons, photons from π^0, η and χ_c decays*
- *Identification of electrons and positrons, participation in muon identification*

Requirements:

- *Granularity ~4 cm*
- *Low energy threshold (~50 MeV)*
- *Energy resolution* $\sim 5\,\%/\sqrt{E}$

RANGE (MUON) SYSTEM



Goals:

- *Muon identification*
- *Rough hadron calorimetry*
- *Yoke of the magnetic system*

Requirements:

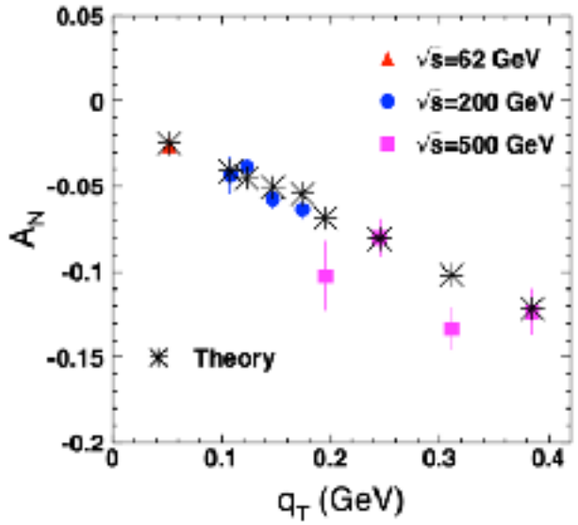
- *should have at least $4\lambda_I$*

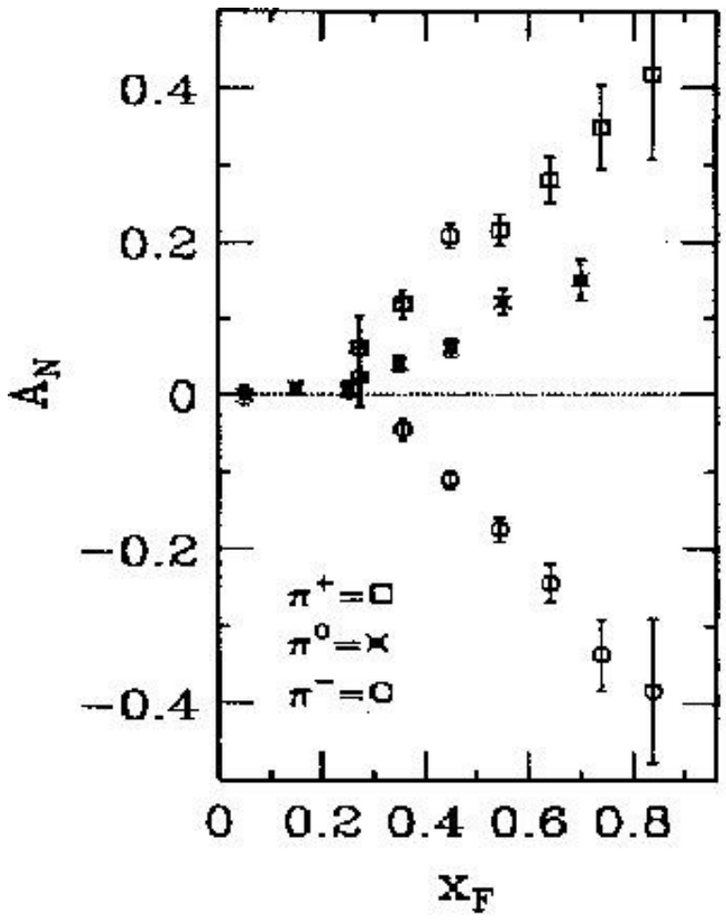
Event examples at 5 GeV/c

LOCAL POLARIMETRY AND LUMINOSITY CONTROL

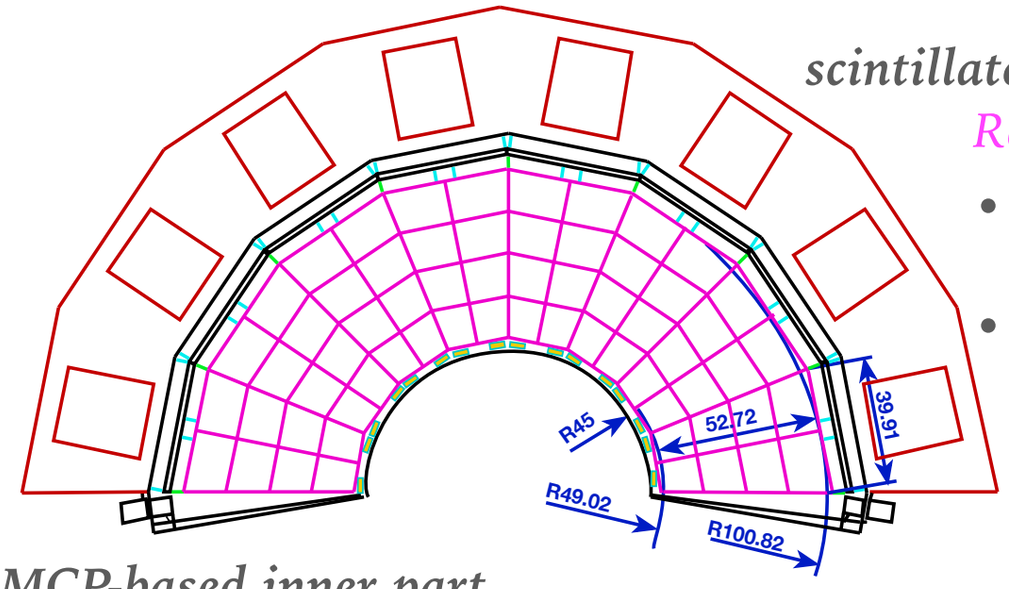
Local polarimetry

- *Charged particles in BBC*
- *π^0 in the end-cap part of ECAL*
- *Neutrons in ZDC*





Beam-Beam Counter

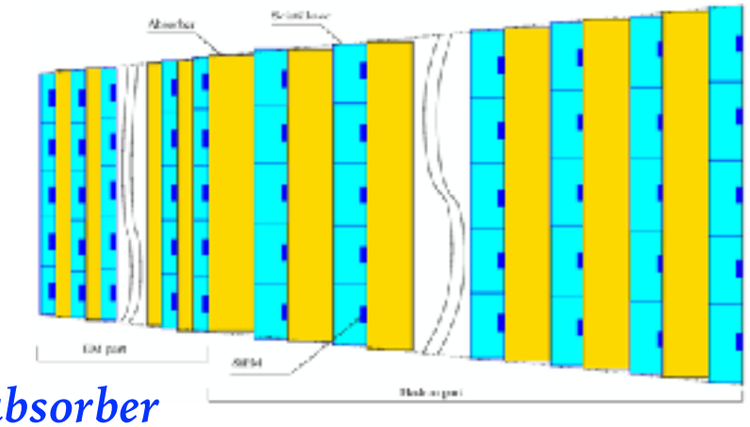


MCP-based inner part

scintillator-based outer part

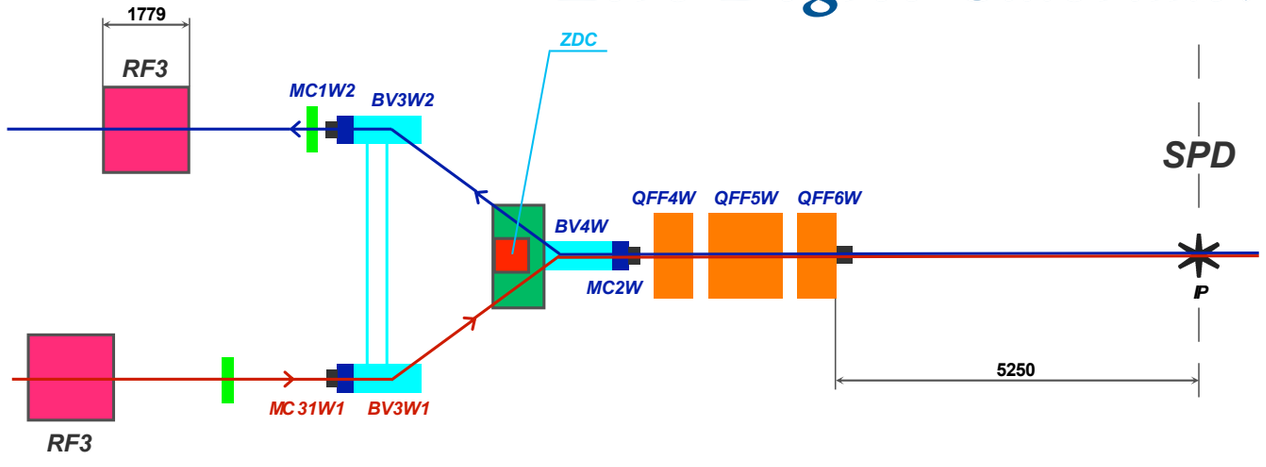
Requirements:

- *Operation inside the beam pipe (inner part)*
- *Time resolution ~1 ns (inner) and ~400 ps (outer part)*



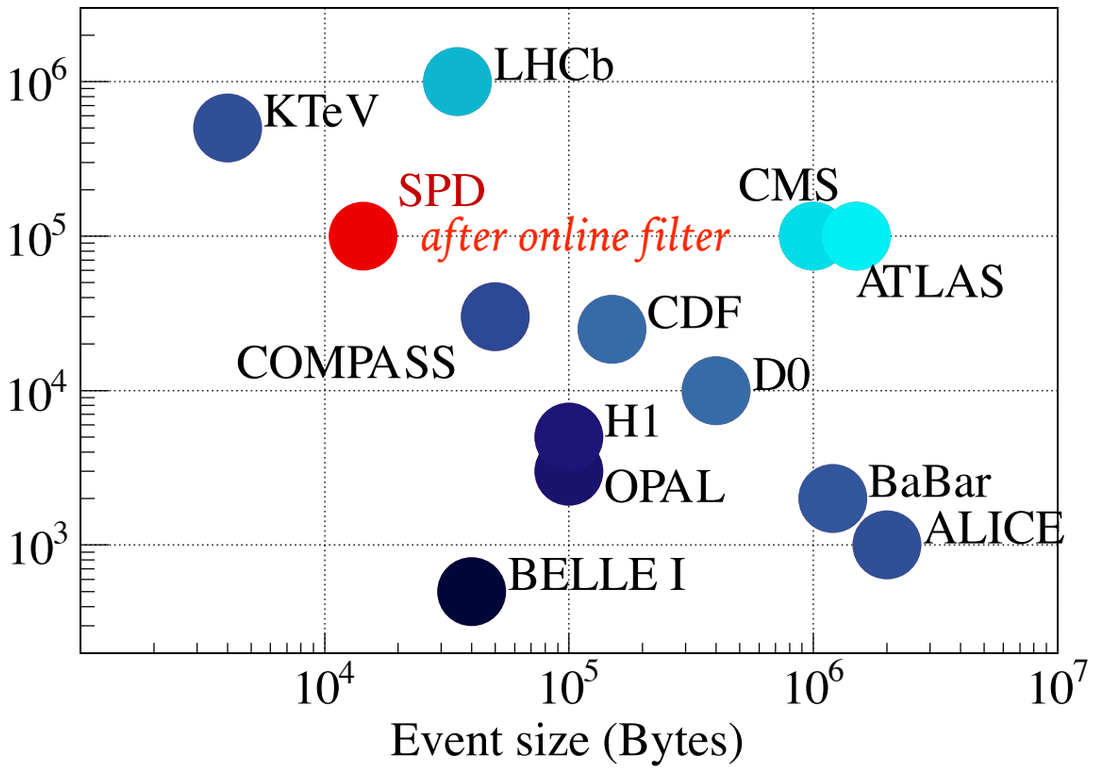
W-absorber

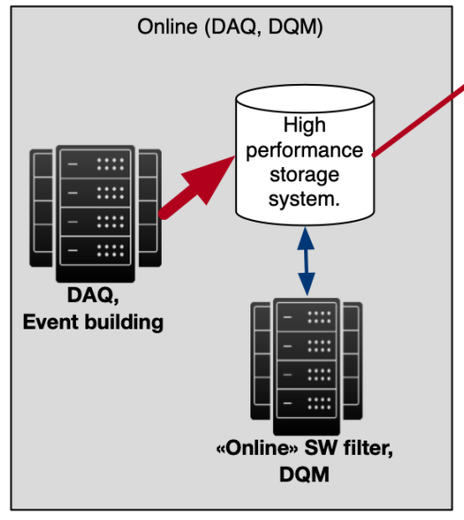
Zero Degree Calorimeter

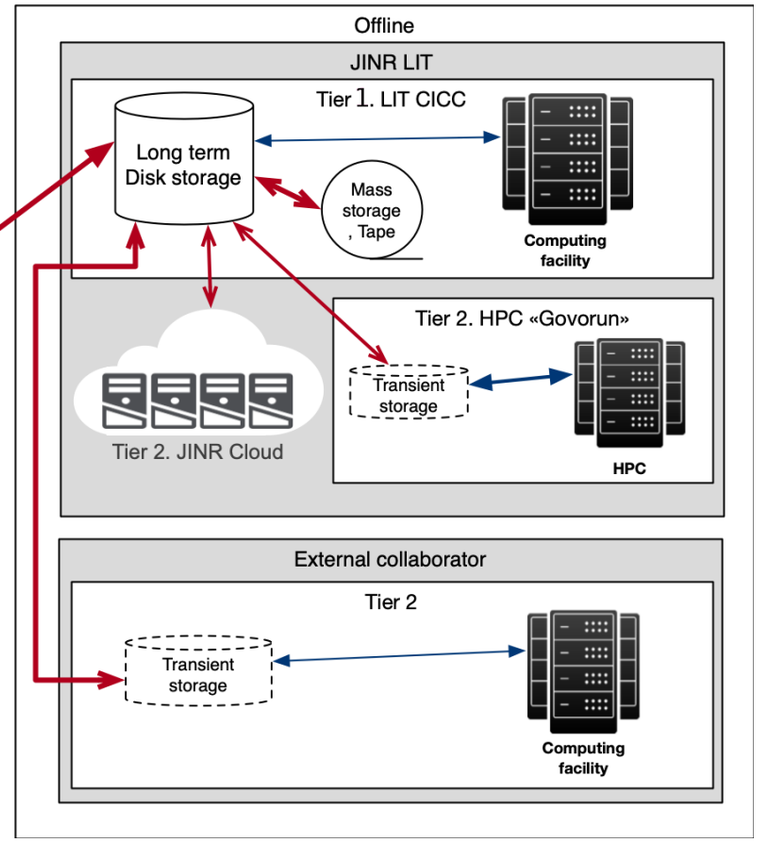


DAQ & COMPUTING

No hardware triggers to avoid possible bias!

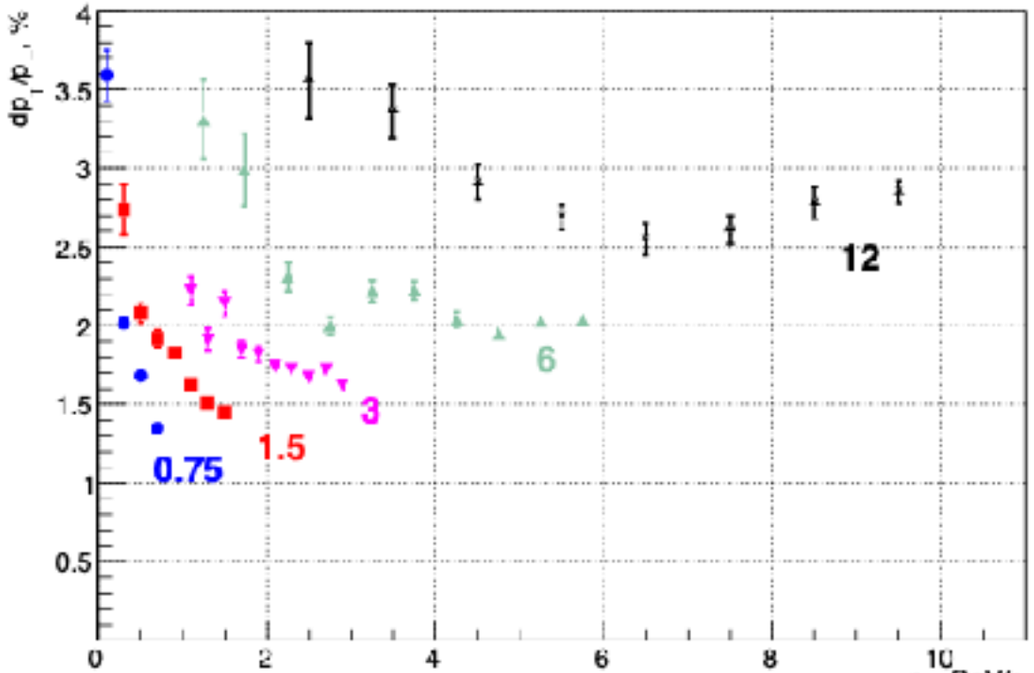


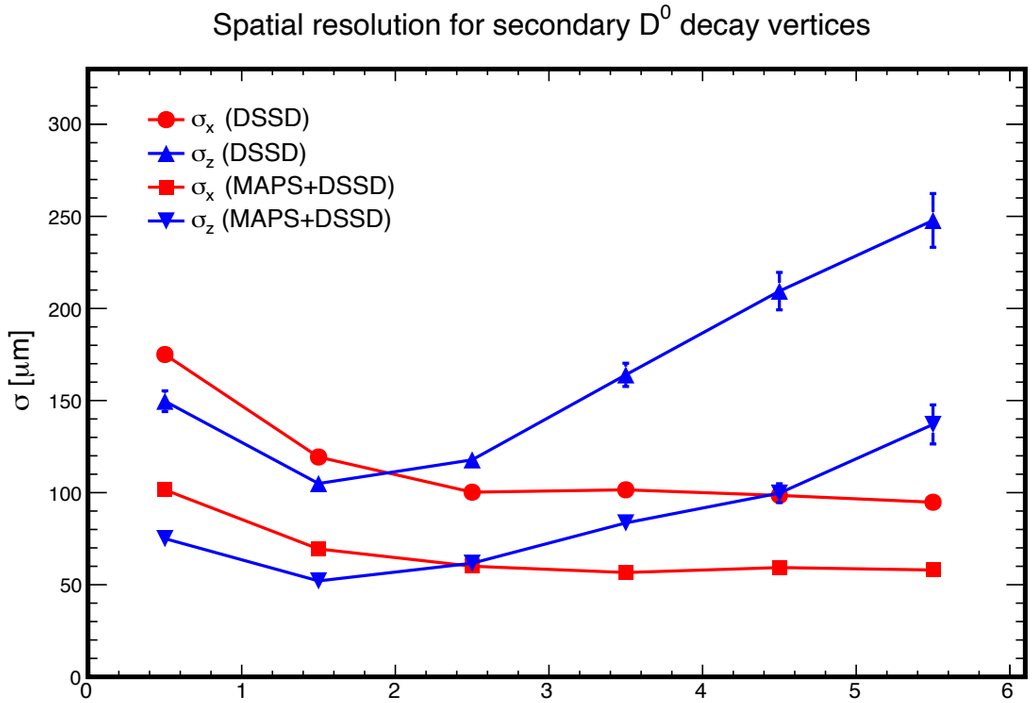


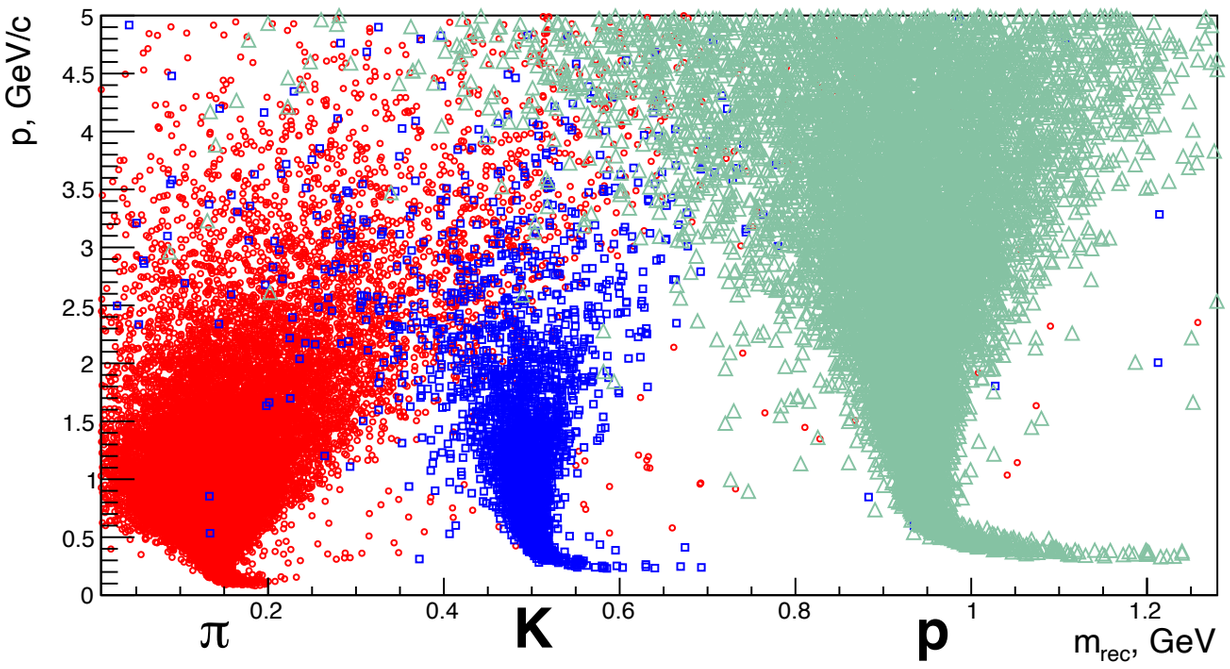


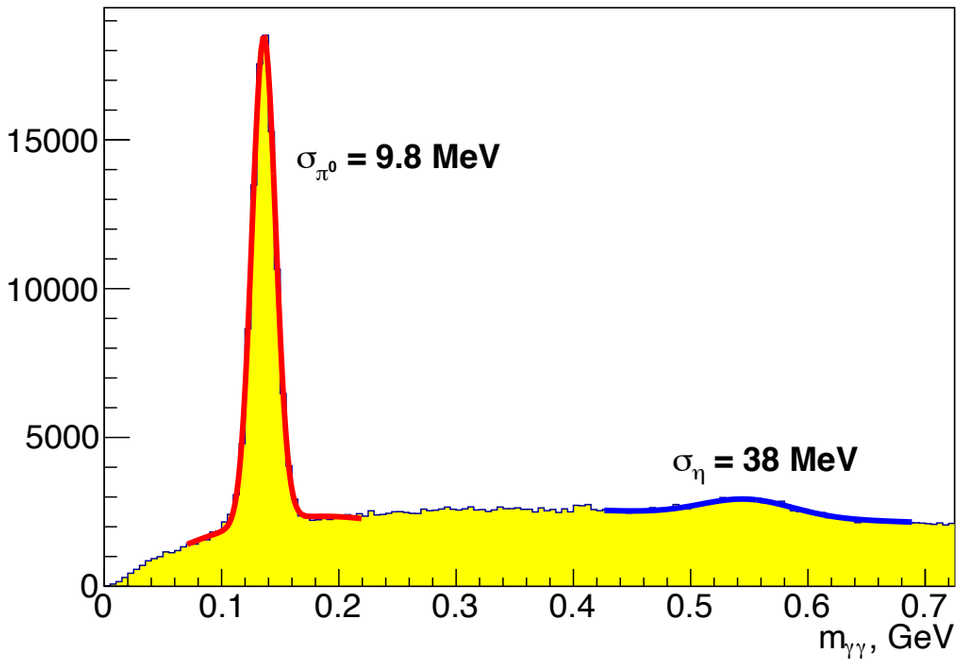
	CPU [cores]	Disk [PB]	Tape [PB]
Online filter	6000	2	none
Offline computing	30000	5	9 per year

DETECTOR PERFORMANCE

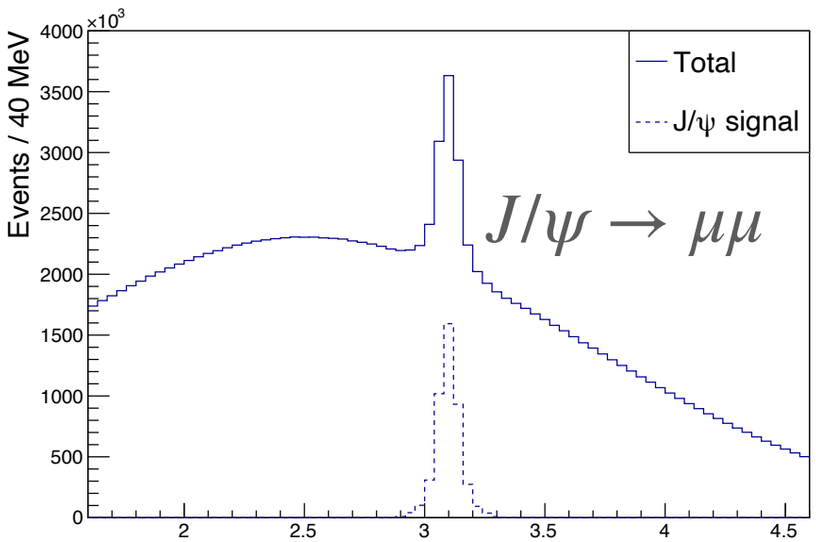


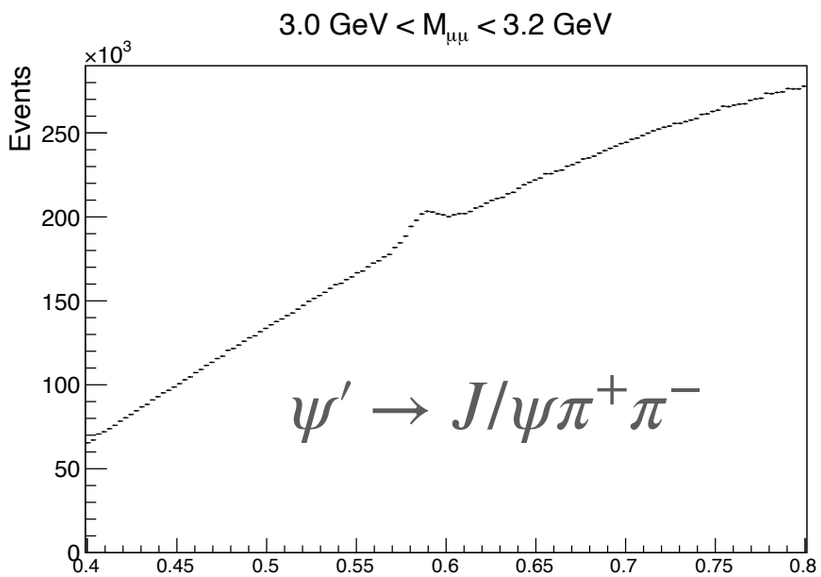


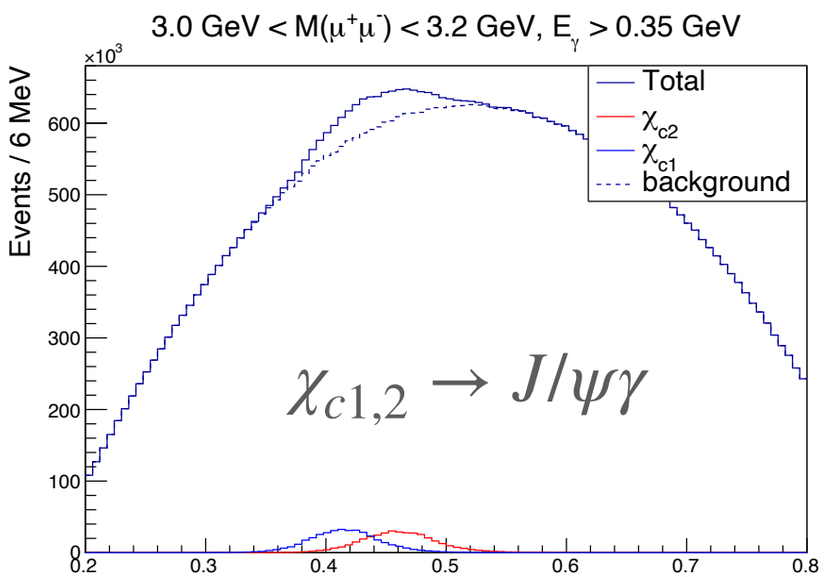


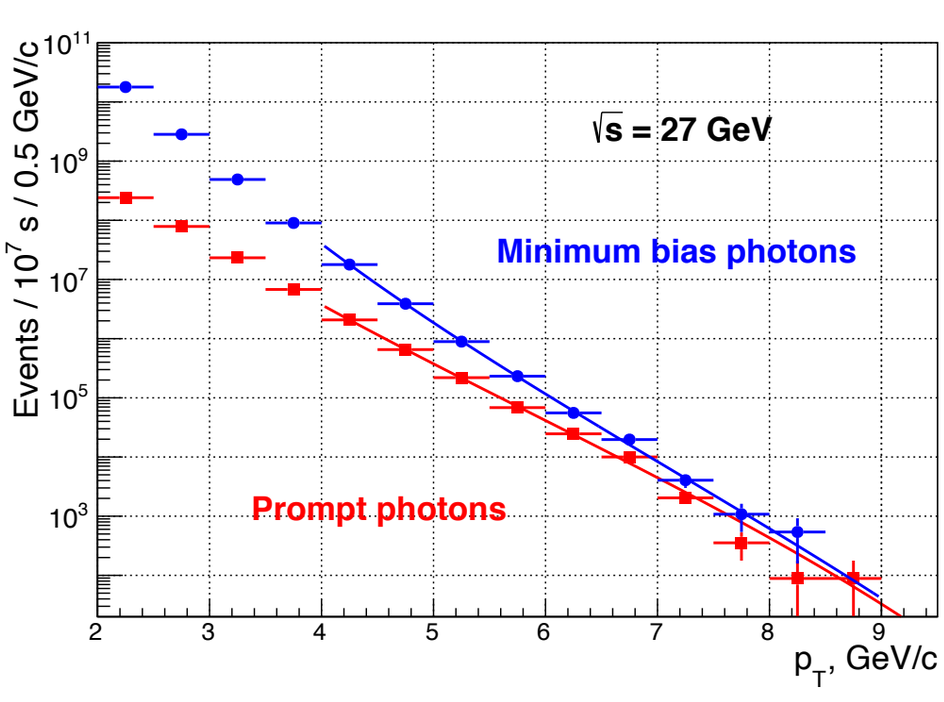


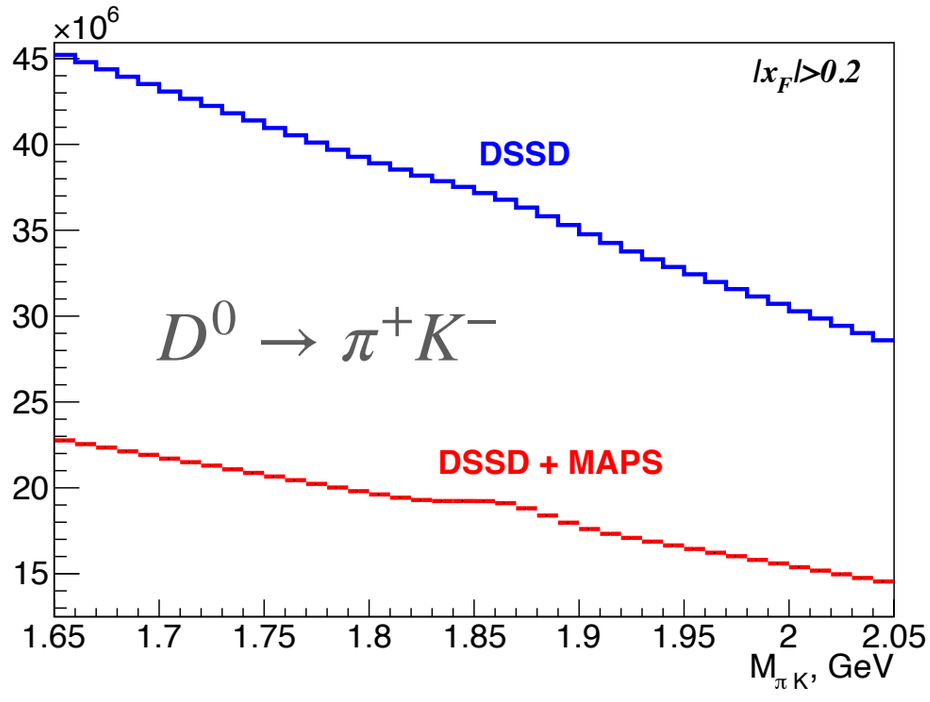
PHYSICS PERFORMANCE: GLUON PROBES (1 YEAR=10^7 S)











TENTATIVE RUNNING PLAN

Physics goal	Required time	Experimental conditions
First stage		
Spin effects in p-p scattering dibaryon resonanses	0.3 year	$p_{L,T}$-$p_{L,T}$, $\sqrt{s}$ <7.5 GeV
Spin effects in p-d scattering, non-nucleonic structure of deuteron, $\bar{p}$ yield	0.3 year	d_{tensor}-p, $\sqrt{s}$ <7.5 GeV
Spin effects in d-d scattering hypernuclei	0.3 year	d_{tensor}-d_{tensor}, $\sqrt{s}$ <7.5 GeV
Hyperon polarization, SRC, ... multiquarks	together with MPD	ions up to Ca
Second stage		
Gluon TMDs, SSA for light hadrons	1 year	p_T-p_T, $\sqrt{s}$ =27 GeV
TMD-factorization test, SSA, charm production near threshold, onset of deconfinment, $\bar{p}$ yield	1 year	p_T-p_T, 7 GeV< $\sqrt{s}$ <27 GeV (scan)
Gluon helicity, ...	1 year	p_L-p_L, $\sqrt{s}$ =27 GeV
Gluon transversity, non-nucleonic structure of deuteron, "Tensor porlarized" PDFs	1 year	d_{tensor}-d_{tensor}, $\sqrt{s_{NN}} = 13.5$ GeV or/and? d_{tensor}-p_T, $\sqrt{s_{NN}} = 19$ GeV

≥ 5 years of data taking

SPD INTERNATIONAL COLLABORATION

~30 institutes from
12 countries +
individual contributors

The SPD international collaboration is forming actively

SPD CDR was issued in the beginning of 2021: arXiv:2102.00442

CDR in now under expertise of the international ***Detector Advisory Committee***

First version of the SPD TDR should be presented in the beginning of 2022

SUMMARY

- The **Spin Physics Detector** at the NICA collider is a universal facility for comprehensive study of polarized and unpolarized **gluon content of proton and deuteron**; in polarized high-luminosity **p-p** and **d-d** collisions at $\sqrt{s} \leq 27\ GeV$
- Complementing main probes such as **charmonia** (J/ψ and higher states), **open charm** and **prompt photons** will be used for that;
- SPD can contribute significantly to investigation of
  - gluon helicity;
  - gluon-induced TMD effects (Sivers and Boer-Mulders);
  - unpolarized gluon PDFs at high-x in proton and deuteron;
  - gluon transversity in deuteron.
  - …
- **The SPD gluon physics program is complementary to the other intentions to study the gluon content of nuclei (RHIC, AFTER, EIC) and mesons (COMPASS++/AMBER, EIC).**
- SPD CDR could be found at arXiv:2102.00442 for more details.
- More information could be found at http://spd.jinr.ru